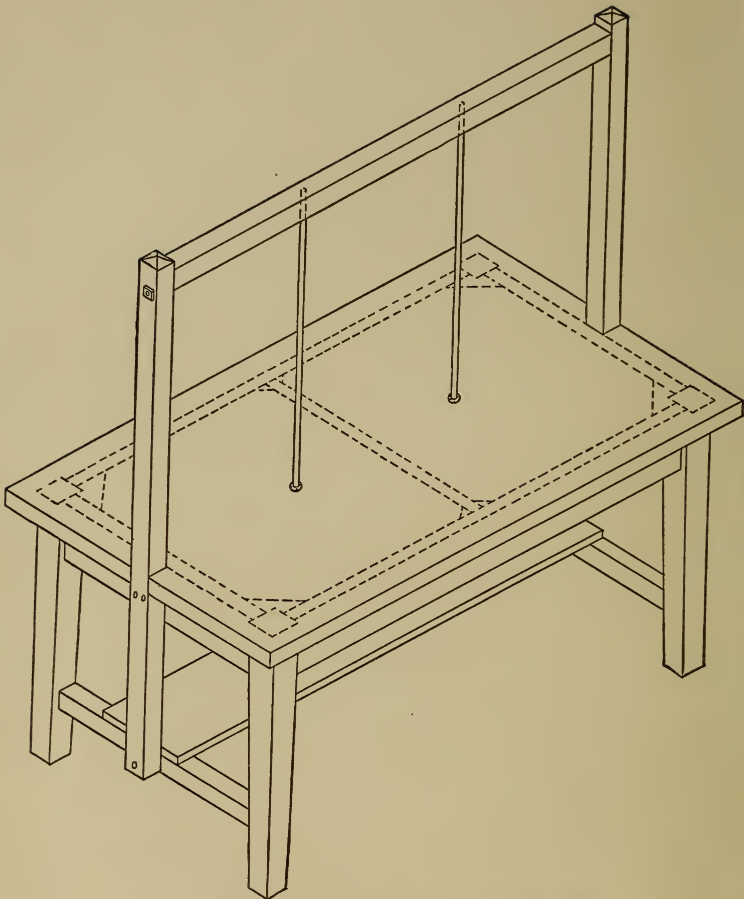

Laboratory table, shown in isometric projection.
Length, 6 ft.; width, $3\frac{1}{2}$ ft.; height of top, 3 ft.
Height of cross-bar above top, 3 ft. 4 in.

LABORATORY EXERCISES

IN

PHYSICS

FOR SECONDARY SCHOOLS

BY

GEORGE R. TWISS

THE CENTRAL HIGH SCHOOL, CLEVELAND

REVISED EDITION

CHICAGO

SCOTT, FORESMAN AND COMPANY

1906

PREFACE

This book presents fifty-seven exercises and fifty-six supplementary or optional problems for the laboratory, and affords ample variety for a selection by the teacher of from thirty to forty experiments for a year's course. These are designed to be used in conjunction with text-book lessons and class-room demonstration.

Adequate material will be found here for fully supplementing any good class book; but the manual is in especially close harmony with the spirit and method of the "Mann and Twiss *Physics*."* The authors of that book recommend the manual for use with their text.

A prominent feature of both the text-book and the manual is the subordination of manipulation to thought processes.

The Author is strongly in sympathy with the new movement which is now gathering force throughout this country and Europe, and which has for its aim the recovery of some of the enthusiasm and vitality of interest which characterized the study of physics a generation ago when it went by the name of Natural Philosophy. We ought not to lose sight of the fact that our main work is to train up sane and

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**Physics*. By C. R. Mann and G. R. Twiss. Chicago, Scott, Foresman and Co. 1905.

competent men and women for the ordinary vocations of life, and not to make physicists.

Attention is respectfully directed to the following features which it is believed will especially commend this manual to thoughtful teachers:

1. By the choice of subject-matter and method of presentation the attention of the student is guided toward the observation of important phenomena and the interpretation of their relations to one another, rather than toward the peculiarities of instruments of precision or the niceties of exact measurement.

2. A majority of the exercises, however, do require measurements of some care, and they all demand attentive observation and clear thinking; but measurements are emphasized, not as an end in themselves, but rather as a means of finding out how phenomena are related to one another.

3. The experiments are simple, interesting, and workable, and represent fundamental principles which the student may find in operation all about him.

4. The apparatus required is all very simple and inexpensive, and no specially designed or unusual pieces are demanded. Nearly all the experiments may be made with such equipment as is already possessed by most school laboratories. With the exception of a very few pieces, the entire equipment may be "home-made" by the teacher and some of the boys who are handy with tools: in fact, a great part of the laboratory apparatus in the Central High School at Cleveland has been so made.

5. The book contains a system of suggestions for

the making of laboratory notes which in the course of the year will train the student to arrange his record methodically and to devise tabular forms for himself. In a number of cases such forms are printed in the book because these particular forms are found to be more suggestive to the student in reaching his conclusions and more convenient for quick inspection by the teacher than any that he is likely to devise for himself.

6. Throughout the work the student is aided by suggestions and pointed questions which clear the difficult portions of his path so that he can proceed alone where it is less difficult.

7. The book has grown into its present form out of the Author's actual experience of twenty years in teaching physics to high school scholars of both sexes and all grades of natural ability. The directions for experimenting have gone through many revisions and thus they have been made so clear and explicit that if the student asks what he is to do or how he is to do it, he may be told to look in his manual for the answer. By a careful re-reading he will almost invariably find the means of answering his own question. This teaches him to rely on his own resources, rather than to lean on the teacher.

8. Since the teacher is thus freed from the wearying and profitless repetition of details, he will have more time and energy left for the broader and more important work of teaching fundamental principles and inculcating correct habits of thought and expression.

Grateful acknowledgment is hereby tendered to Prof. Frank Perkins Whitman, of Western Reserve University, and to Mr. Franklin Turner Jones, of the University School, Cleveland, for their thorough and critical reviews of the manu-manuscript and proof sheets of the first edition. The Author also hereby extends his hearty thanks to Prof. Charles Riborg Mann, of the University of Chicago, who has been his active adviser in the preparation of the present revised edition, and to whose wise suggestions much of the improvement is due.

GEORGE RANSOM TWISS.

Cleveland, August 27, 1906.

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TO THE STUDENT

The Laboratory is the place to test and apply what you learn in the class room. The value of the training that you will get out of it will depend on the faithfulness with which you carrry out the instructions of your teacher and of this book.

Punctuality.—Begin and stop your work promptly at the proper signals.

Attention.—Keep your attention fixed on the work in hand. Listen carefully to every suggestion of the instructor. Never speak except in a whisper or low undertone.

Order.—Preserve an orderly arrangement of apparatus while at work. See that things are always in the positions where they can be used most readily and conveniently.

Neatness.—If the apparatus or the table becomes dusty or wet, dry or clean it immediately. If you find anything at your table in bad condition report it to the teacher before beginning work. Do not leave papers or litter on floor or tables. Deposit them in the receptacles provided for them.

Explanations.—Do not ask questions of your fellow students unless you are directed to consult with them. Do not ask a question of the teacher until you have looked carefully for the answer in your

laboratory manual and text-book and failed to find it there.

Sinks.—Never throw anything into the sinks excepting water.

Preparation.—Study carefully each Exercise before the laboratory hour. Do not try to commit directions to memory, but *think out* everything they tell you to do. Try to comprehend the plan of the work, and picture to yourself just how you will carry it through. Where your previous instruction has prepared you for it, try also to think out the kind of results you may reasonably look for and the conclusions you may possibly reach.

Prepare the page upon which your notes are to be taken. Have tabular forms ruled and spaces allotted for the different kinds of notes.

Carefulness.—Keep the plan and purpose of the experiment constantly in mind. Observe keenly everything that happens during your experiment, and when measurements are to be made get the values as accurately as you can with the apparatus provided. Record phenomena and numerical data just when they are observed. Record exactly what you observe, not what you think you ought to observe. You cannot acquire the scientific spirit or get the value of the laboratory training unless you are absolutely honest with your own intellect.

Note Books.—Never make notes or calculations on loose paper. Keep them all in your note book.

Do not erase numerical data. Enclose rejected

matter in brackets and write "rejected" at the side of it.

Express fractions and ratios decimally. Do not crowd the notes together. Arrange them systematically and leave generous spaces between different parts of the subject-matter. Label calculations and diagrams, and make the paragraph headings prominent. In other matters pertaining to your notes, follow carefully the directions given you by the teacher.

Borrowing.—Never borrow a note book from another student, or lend your own without permission from the teacher. Never take apparatus from one place to another in the laboratory unless so directed.

ABBREVIATIONS USED IN THIS BOOK

Art.	Article, paragraph.
A.	Acceleration.
B.	Barometric reading.
Cf.	Compare.
cc.	cubic centimeter.
cm.	centimeter.
$cm.^2$	square centimeter.
$cm.^3$	cubic centimeter.
$\frac{cm}{sec}$	centimeter per second.
$\frac{cm}{sec^2}$	$\frac{cm}{sec}$ per second.
D	density.
Ex.	Exercise.
F., f.	force.
gm.	gram.
g.	the acceleration of a freely falling body.
h.	height.
K	any constant.
l	length or distance.
M, m	mass.
m.	meter.
mm.	millimeter.
R, r	radius.
sec.	second.
T, t	time, period.
v	velocity.
V	volume.
W, wt.	weight.

TEXT-BOOK REFERENCES

The text-books referred to by paragraph numbers at the beginning of each exercise are named below:

M & T . Physics. Mann & Twiss. Scott, Foresman and Co.
A . . . . School Physics. Avery. Butler, Sheldon & Co.
C . . . . Elements of Physics. Crew. The Macmillan Company.
C & C . . High School Physics. Carhart & Chute. Allyn & Bacon.
GE . . Elements of Physics. Gage. Ginn & Co.
GP . . . Principles of Physics. Gage. Ginn & Co.
H . . . . A Brief Course in Physics. Hoadley. American Book Company.
H & W . Elements of Physics. Henderson & Woodhull. D. Appleton & Co.
J . . . . Heat, Light and Sound. Jones, D. E. The Macmillan Company.
J & J . . Elementary Electricity and Magnetism. D. C. & J. P. Jackson. The Macmillan Company.
L . . . . Elementary Mechanics. Lodge. The Macmillan Company.
T . . . . Elementary Lessons in Electricity and Magnetism. Thompson. The Macmillan Company.
W & H . A Text-Book of Physics. Wentworth & Hill. Ginn & Co.

Laboratory Exercises in Physics

CHAPTER I

MECHANICS OF SOLIDS

Exercise Number 1

TIMING A PENDULUM

References

C 17	H 17	M & T 2
GP 3	H & W 39	

The Purpose of the experiment is to determine the time of oscillation of a pendulum, in order to use it as a time measurer in experiments with freely falling bodies.

The Apparatus consists of a laboratory clock or watch, and the pendulum (*P* Fig. 1, p. 2), consisting of a flat strip of wood with a pair of movable weights for a bob. It is suspended from a firm support by means of a strip of flexible leather.

Operations.—(*a*) One observer, A, sees to it that the second hand of the time piece is set so as to come to zero at the instant when the minute hand marks an even minute. Another observer, B, draws the pendulum aside through a small arc. A notes the hour, and when the second hand is nearly at zero,

says "Ready!" Just when the second hand reaches zero, he says "Now!" and B instantly lets go the pendulum, being very careful not to push it. He then counts the double swings of the pendulum, beginning with "One" when the pendulum completes its first double swing, or round trip. A, meanwhile watches the time, and notes the minute and second when he said "Now."

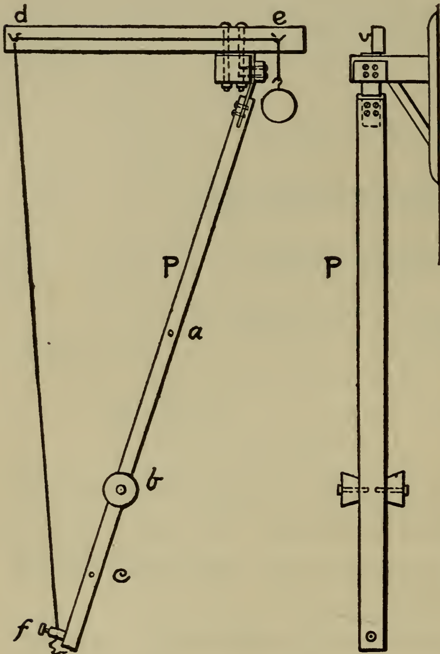

Fig. 1.

(*b*) When the time agreed on, say 100 sec., has nearly elapsed he again says "Ready." B then follows the motion of the pendulum with his hand, keeping in time with its rhythmic motion, so he can stop it just where it is when A gives the word. When the 100th second is completed, A says "Now!" and B stops the pendulum. He then states the number of single oscillations and the decimal fraction of a single oscillation made by the pendulum between the instants of starting and stopping.

By a single oscillation is meant a swing from one extreme position to the other, as distinguished from a complete vibration, or swing to and fro. A and B should exchange places after each trial.

A more accurate, but somewhat more difficult method is to observe the time, first when the pendulum passes its lowest point, and again when it passes this point in the same direction after say 30 complete vibrations. In this case the fractional parts of a second must be estimated, and expressed to tenths.

If a stop watch is provided, it affords the simplest and most accurate means of measuring short time intervals for beginners, as it always starts at zero and stops at an even fifth of a second.

Data and Calculations.—Calculations should be entered in full on one of the left hand pages of the note book, and the final results tabulated as suggested by the annexed ruled form. In the calculations retain four figures (cf. Appendix A, Art. 3 and 4). A set of these observations should be made with the weights at (*a*), another set with them at (*b*), and a third set with them at (*c*).

Observations made by.........................and.........................

SECONDS	OSCILLATIONS	TIME OF OSCILLATION
		Sec.
		"
		"
Mean time, Weights at (*a*).........................		
		"
		"

Errors.—State briefly the sources from which errors,

personal and instrumental, are likely to arise. (Cf. Appendix A, Art. 1.)

Lessons.—This exercise is preliminary to Exercise 2; but incidentally the student may learn several things in connection with the phenomena which he has had opportunity to observe. Let each one answer in his note book, in complete sentences, the following questions:

(*a*) Are the oscillations made in equal times even though they are made through unequal arcs, provided the arcs are small?

(*b*) At what position does the pendulum bob have its greatest velocity? What velocity does it have at either end of the swing?

(*c*) What fraction of the time of oscillation is required in going from either extreme position to the middle?

(*d*) If a clock gains or loses time, what may be done with its pendulum in order to regulate it?

Exercise Number 2

STUDY OF A FALLING BODY

References

A 18, 19, 101–108	GE 5, 10–13	H & W 68–76
C 9, 25–29, 81–86	GP 2, 10–14	L 7–12
C & C 8, 31–34	H 12, 78–84	M & T 2–20
	W & H 10, 166–171	

The Purpose is to find out what distances a body traverses when it starts from rest and falls for different time intervals, and to determine the acceleration.

The Apparatus (cf. Appendix F, Art. 1) consists of the pendulum that was rated in Exercise 1, a heavy ball, a meter stick, and a stick of bicycle graphite.

Operations.—(*a*) A strip of manila paper of the same length and width as the wooden rod of the pendulum, is attached to the rod with thumb tacks or soft wax (cf. Appendix H, Art. 1). The ball is coated with graphite, and hooked into a loop at one end of a long cotton string, which is then passed over the two hooks *d* and *e*, and fastened in the binding post *f* at such a point that the ball hangs with its center just at the upper end of the pendulum rod, while the pendulum is drawn back by the string as shown in Fig. 1, p. 2.

Before thus arranging the apparatus, the hook *e* should have been adjusted in such a position that the ball, when hanging as a plumb-bob, will just touch the face of the rod at any point of its length, while the latter is hanging freely in its vertical position.

(*b*) After seeing that the pendulum and the ball are perfectly motionless, the observer burns the string with a match. This releases the ball and pendulum at the same instant; and the pendulum, just as it completes a half oscillation, strikes the ball, so as to print a black spot on the paper. If the weights were at a, mark this spot a_1. In exactly the same way, make one or two other trials, and mark the spots a_2, a_3, etc.

(*c*) If time permits, another set of trials should be

made with the weights at b, and a third set with them at c. The spots should be marked b_1, b_2, c_1, c_2, etc.

(d) The paper strip is now removed and laid flat on the table. The distance from each of the spots to the upper end of the paper is to be measured in centimeters to the tenth of a cm. (and also, if the instructor so directs, in inches to the sixteenth of an inch. In this case the results should be reduced to feet and hundredths of a foot). In measuring, the meter stick should be set on edge, so that the scale divisions are in contact with the paper, and the observer should sight along the division line of the scale, where the reading is taken, so as to avoid the error called *parallax*. Care should be taken also that the measurement is made along a straight line.

Data.—Place the results in a neatly ruled tabular form, as suggested below.

NUMERICAL DATA

Observations made by..

Position of weights	a	b	c
Time (of single oscillation) $= t$			
Distance, 1st trial			
" 2d trial			
" 3d trial			
" mean $= l$			
Acceleration $= \frac{2l}{t^2}$			
Mean value of the acceleration from a, b, and c,			
Per cent error			

Calculations.—The average velocity is the distance l divided by the time t; the final velocity is twice the average velocity, or $\frac{2l}{t}$; and the acceleration, $a = \frac{2l}{t^2}$, *i.e.* the change of velocity $\frac{2l}{t}$ divided by the time t.

Sources of Error.—When the pendulum bob is in its lowest position, that in which it would come to rest, it is assumed in the experiment that the face of the rod is in the vertical line along which the ball falls. If this is not true, the paper will meet the ball either before or after the instant when the pendulum has completed a half oscillation, and the distance measured will be that fallen in a less or a greater time than that assumed. A similar error will be caused if the ball is swinging toward or from the pendulum at the time of beginning its fall. What other sources of error can you name?

Inferences.—(*a*) Are the values of the acceleration nearly enough equal so that we may think the differences due to experimental errors?

(*b*) If so, may you say that, so far as your experiments go, the acceleration of the falling ball is constant?

(*c*) The acceleration being the ratio of change of velocity to time, and being constant, may we say that the changes of velocity of a freely falling body are proportional to the times of falling?

(*d*) Since also the acceleration is twice the ratio of the distance fallen to the square of the corresponding

time, if this acceleration is constant, may we say that when a falling body starts from rest, and falls for different time intervals, the distances traversed are directly proportional to the squares of the times of falling?

Exercise Number 3

GRAPHICAL REPRESENTATION OF ACCELERATED MOTION. VELOCITY—TIME

References

M & T 4, 5

The Purpose of this exercise is to find out what kind of diagram will represent the way in which the velocity varies with the time in the case of the falling body of Exercise 2.

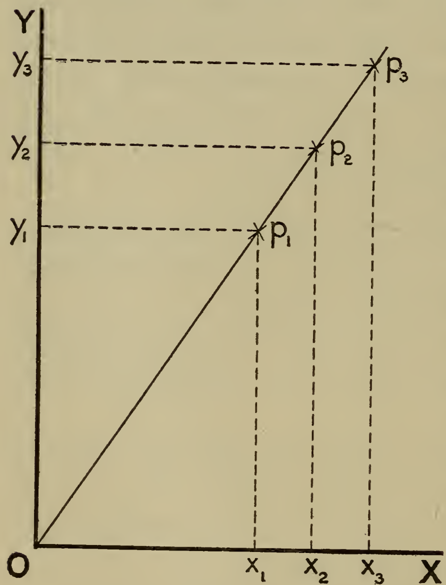

Fig. 2.

Operations. — Near the lower left hand corner of the note book page, or of a sheet of squared paper, choose a point *O* (Fig. 2) at the intersection of two lines. This point will be called the *origin*. From the origin, draw two

heavy lines, OX horizontal, and OY vertical. Label OX "Axis of Abscissas. Times," and OY "Axis of Ordinates. Velocities." Below OX write "Scale, 1 cm. = 0.15 sec.," and at the left of OY write "Velocities. Scale 1 cm. = 100 $\frac{\text{cm.}}{\text{sec.}}$."

(*b*) The times are to be represented by distances from OY measured in the direction OX; and the velocities by distances from OX measured in the direction of OY. The scale according to which the quantities are represented must be of such a magnitude that the diagram will be of convenient size for the page.

(*c*) From your data for Exercise 2, take the values of t, divide each by the scale number (0.15 in this case), to find the number of cm. by which each value of t is to be represented in the diagram. Similarly, for the corresponding velocities, divide each by 100. Enter the times, the corresponding velocities, and the numbers that are to represent them in a neat tabular form near the diagram.

(*d*) The first point of the diagram is that which will represent the instant of starting. This is the instant from which we begin to count both time and velocity, so the time elapsed is zero, and the velocity gained since the instant of starting is also zero. Evidently the point O represents both time and velocity at this instant, and is therefore the first point of the required diagram.

(*e*) For the next point, lay off from O on OX the number of cm. that is to represent the smallest value of t; and mark the point x_1. Similarly, lay off from

O on OY the number of cm. that is to represent the velocity gained during this time, and mark this point y_1. From x_1 draw a vertical dotted line, and from y_1 a horizontal dotted line intersecting the vertical at a point p_1. This point represents the first time of falling, since its distance from OY is proportional to that time; and it also represents the velocity gained during that time, because its distance from OX is proportional to that velocity.

(f) The point p_2, representing the next smallest time of falling and the corresponding velocity, is found in exactly the same way. Similarly for the points p_3, p_4, etc. representing other times and the corresponding velocities. *The abscissas and ordinates are always to be measured from O;* and the times and corresponding velocities are all to be *the total values from the instant of starting.*

(g) The diagram, or graph as it is called, is completed by drawing the straight line, or the smooth curve (whichever it may be) that most nearly passes through all the points O, p_1, p_2, etc. To look well, this line should be drawn with a draftsman's pen and red ink. If the line is curved, the pen should be guided by a "French curve" or a piece of whalebone.

(h) Label the graph, "Freely Falling Body. Relation of Changes in Velocity to Corresponding Times." The distances Ox_1, Ox_2, etc. are the *abscissas*, and the distances $x_1p_1 = Oy_1$, $x_2p_2 = Oy_2$, etc. are the *ordinates*, of the points p_1 p_2, etc. The abscissa and ordinate of a point are called its *co-ordinates.*

Inferences.—Answer in complete sentences. (*a*) Is the graph just drawn a straight line? If it is straight, can you prove by similar triangles that the ordinates are proportional to the corresponding abscissas?

(*b*) If so, since the abscissas represent times and the ordinates the corresponding gains in velocity, what relation does the straight line graph show exists between the velocities gained and the times in which they were gained?

(*c*) Does the uniform slope of this velocity-time graph mean that the body whose motion it represents is gaining velocity at a constant rate, *i.e.* that its acceleration is constant?

Exercise Number 4

DISTANCE-TIME GRAPH FOR UNIFORMLY ACCELERATED MOTION

References

M & T 4, 5, 12, 13

The Purpose is to find out what kind of graph will represent the relation between the times of falling and the total distances traversed in those times, in the case of the falling ball of Exercise 2.

Operations.—Proceed exactly as in the preceding exercise, except that the ordinates are now to represent the distances traversed in the various times instead of the velocities gained. The scale for the times may be 1 cm. = 0.1 sec., and the scale for the distances, 1 cm. = 20 cm.

Inferences.—(*a*) Does the slope of the graph increase, decrease, or remain constant? (*b*) The slope now represents the velocity, not the acceleration (*i.e.* the ratio of change of distance to time instead of the ratio of change of velocity to time). Does the slope show that this velocity is constant, or variable? Increasing, or decreasing?

NOTE.—This graph belongs to a class of curves called *parabolas*. The characteristic peculiarity of a parabola is that the abscissas vary in direct proportion to the squares of the ordinates, or vice versa. If we get such a curve from the data of an experiment, we may infer from it that one of the quantities represented by it varies as the square of the other. In this case, the distance varies as the square of the time, as we found by inspection of the tabulated data of Exercise 2. If we find, as in this case, that a graph appears to be a parabola and are not sure that it is one, we cannot infer with certainty that the ordinates are proportional to the squares of the abscissas (*i.e.* as in this case of the falling body that the lengths are directly proportional to the squares of the times). A quick and easy way of testing the matter is to plot a new graph, with the same ordinates but with the former abscissas *squared*. (In this case represent the values of l by the ordinates as before and the *squares* of the corresponding values of t by the abscissas.) If the resulting graph is a straight line we may then be sure that the relation represented by the first graph is what we supposed it to be, *i.e.* that the ordinates are proportional to the squares of the abscissas (or in this case that the distances are proportional to the squares of the times). A little thought about the use of the graphical method will convince the student that it is very useful in discovering what relation exists between the values of two quantities (like l and t in Exercise 1), one of which changes in value whenever the other is changed. Thus a graph may tell us whether the distances are directly proportional to the times, or directly proportional to the squares of the times, or inversely proportional to the times, and so on.

Exercise Number 5

COMPARISON OF MASSES BY THE ACCELERATION METHOD

Note.—The experience gained in this experiment is very useful for fixing in mind the relations of force, mass and acceleration; but in the case of many pupils it requires considerable practice before good results can be obtained. In case the teacher thinks best to omit it from the laboratory course, the author advises giving it, at least roughly, at the demonstration table.

References

A 27, 11, 60–66
C 2–7, 14, 16–21, 25–29, 33, 34, 45, 50, 51, 54–56, 58, 63
C & C 30–34, 39–44
GE 10–12, 22, 26, 27, 31–34
GP 9–11, 29, 32–38, 41, 44, 63, 78
H 35–40, 44–46
H & W 62–65, 67
L 1–12, 29–36, 41–49
M & T 9, 22–28, 31
W & H 16, 17, 161, 168, 174, 178–183

Purpose. — The purpose of this exercise is to apply equal forces to two masses for equal time intervals, and to determine whether the greater or smaller mass acquires the greater velocity; to determine whether their masses are equal if with forces equal they receive equal accelerations; and to learn what degree of accuracy is possible in adjusting masses to equality by this method.

Apparatus. — The apparatus is as follows: Two cars, provided with hooks or screws at front and rear; two rubber bands or strips of pure gum tubing, r, r_1, of equal lengths and elastic forces, and with loops at their ends; two smooth boards, B, B_1, with

hooks near their ends; a supply of lead weights or of iron nuts and nails; a spring balance, or a pair of trip scales and weights; a small S-shaped hook of stiff wire.

Operations. — (*a*) By means of the S-hook join the two bands and stretch them over a measuring stick, so that the ends of the bands are at the ends of the stick. If their elastic forces are equal when they are equally stretched, the junction will be at the middle of the rule. Why? If the S-hook does not lie exactly over the middle division, the stronger band must be trimmed along its edge until the hook remains in the right position.

(*b*) Place a load of nails and nuts in one car, and of nails only in the other; attach the rubber bands to the cars and to one of the pairs of hooks in the boards; draw back the cars until the bands are stretched far enough to give the cars *moderate* velocities. Now secure the cars by a piece of twine, looped upon the two hooks in the backs of the cars and passed around the second pair of hooks in the boards.

(*c*) Adjust the cars so that their

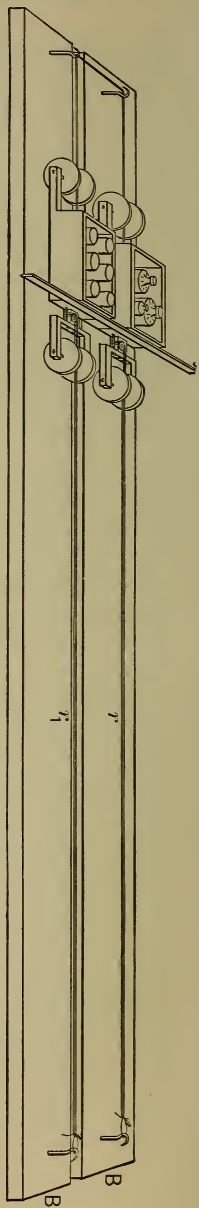

Fig. 3.—Showing cars in position.

front edges are in the same line and the bands equally stretched.

(*d*) Hold a rule between the cars and the two front hooks, and parallel with the line of the front edges of the cars, so that the car boxes, but not the wheels, will strike the rule about where the rubber bands cease to pull.

(*e*) With a lighted match, burn the twine between the two rear hooks, in order to release both cars at the same instant.

(*f*) Note which car has the greater mass as indicated by the velocity which the tension of the rubber band imparts to it, and, by repeated trials, adjust the masses till the cars have equal velocities, which will be when they start and arrive at the same instant. The adjustment should be made by adding, say, eight nails at a time to the car of lesser mass. When the addition of eight nails causes this car to arrive later than the other, remove as many as necessary of this last eight, — one or two at a time.

(*g*) Test the accuracy of the adjustment by determining the least number of nails which must be added, first to one load and then to the other, in order to cause a *clearly perceptible* difference in the time of arrival.

(*h*) When the adjustment is completed, determine the mass of each car and its load by the method of weighing, with the trip scales, or in a pail suspended on the hook of the spring balance, estimating the fractions of scale divisions in tenths.

(*i*) If time permits, repeat with different masses.

Observations. — (*a*) When the forces are equal and the masses evidently unequal, which mass is given the greater velocity?

(*b*) What is the effect, upon the velocity, of increasing the mass?

(*c*) What is the effect, upon the velocity, of increasing the force? (This can be done by stretching the band farther.)

Data. — Let m = mass of first car and load, m' the mass of the second car and load, R and R' the first and second readings of the balance, P the mass of the pail (to be subtracted from R and R' to obtain m and m'), and n the least amount of additional matter (grams) required to cause an observable change in velocity. If a trip balance is used, the pail will not be needed, and then m and m' are obtained directly. The only quantities to be tabulated will be m, m', and n.

NUMERICAL DATA

TRIALS	R	R'	P	$R-P=m$	$R'-P=m'$	n
1						
2						
3						

Calculate and record your per cent error.

Theory. — Let v and v' be the velocities of the cars, t and t' the time intervals during which they travel,

and F and F' the forces applied; then $F = \frac{mv}{t}$ and $F' = \frac{m'v'}{t'}$. (Force is measured by the product of mass and acceleration.) But $F = F'$ (hypothesis), hence $\frac{mv}{t} = \frac{m'v'}{t'}$. Also $v = v'$ and $t = t'$ (because the cars start and arrive at the same instants, and pass over equal distances). Therefore dividing both members by the common factor $\frac{v}{t}$ or $\frac{v'}{t'}$ (which is the acceleration) we have $m = m'$.

Sources of Error. — Some of the most important errors result from —

(*a*) Parallax and personal equation in reading the balances and observing the arrival of the cars.

(*b*) Inequality of the forces. The bands should be tested frequently and readjusted if necessary.

(*c*) Difference in friction of the two cars. This difference, if it exists, can be eliminated by slightly tilting the boards by means of wedges until each car when started will move down its incline with uniform speed.

Inferences. — (*a*) Do your observations and results confirm the deductions of the theoretical discussion above?

(*b*) Make a general statement of what has been deduced and verified.

(*c*) Explain briefly how you would use this method to measure out a pound mass of sugar or coffee at a place where you could not make use of the weight method.

Exercise Number 6

DENSITY OF A REGULAR SOLID

References

A 155	GE 6, 114	H &W 59
C 49	GP 147, 148	L 32
C & C 140, 141	H 145	M & T 28, 31, 32
	W & H 15	

The Purpose is to find out how many grams of matter there are in a cubic centimeter of a given regular solid, *i.e.* to determine the density of the substance of which it is composed.

Operations.—(*a*) Determine the volume of the solid by the method or methods designated by the instructor, and in accordance with the directions given in Appendix C.

(*b*) Determine the mass of the solid with the equal arm balance, trip scales or Jolly balance, according to the choice of the teacher. Follow the directions for the method chosen, which will be found in Appendix D.

Data and Calculations.—Since the density is the number of grams in one cubic centimeter, it is expressed by the quotient obtained by dividing the number of grams by the number of cubic centimeters, and is denoted by the symbol $\frac{gm}{cm^3}$, read grams-per-cubic-centimeter. Label all parts of the calculation, so that it will explain itself. All the individual measurements of the dimensions and the weights should be tabulated in neat parallel columns similar to those used in the preceding exercises. If

the volume or the mass has been determined by more than one method, the mean, or average volume or mass should be used in calculating the density.

Record the name, form, and substance of the solid used.

Lessons.—(*a*) State any ways in which you think a knowledge of the density of a substance may be useful.

(*b*) Supposing you know the density of a chip from a large, regular block of stone, explain how with the aid of this knowledge and a metric rule you could find the mass of the stone.

Exercise Number 7

ELASTIC FORCE OF A HELICAL SPRING

References

C 111 GP 40 W & H 23–25
M & T 305

The Purpose of this experiment is to find out what effect equal additions of force will have upon the length of a helical spring, and to learn how such a spring may be used as a dynamometer (*i.e.* a measurer of forces).

Apparatus.—(*a*) The spring Fig. 4 is suspended from a convenient support, and has a marker near its lower end, which moves over a convenient scale of equal parts, such as a metric rule. The common spring balance is such a spring, and has a scale of equal parts. The units of this scale may be marked pounds, ounces, or grams; and these units may be

again divided into fractional parts. (*b*) There may be either a hook or a pan for suspending masses so that the weights of these masses will pull on the spring, and extend it more or less according to the magnitude of the pull. (*c*) A set of masses, such as the so-called weights used with a common balance is provided, for exerting these pulls.

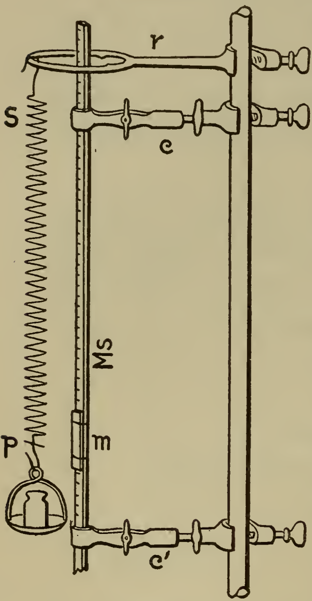

FIG. 4.

Operations.—(*a*) A reading is first taken with no load on the spring. If a spring balance is used, and it is correct, the scale reading corresponding to no pull will be zero. In reading the positions of the points on the scale, great care should be taken to have the eye on the level with the point on the scale at which the reading is taken: otherwise the reading will appear to be greater or less than it really is. This kind of error is called *parallax* and it may be almost entirely avoided by placing a small mirror behind the marker, and keeping the eye in such a position that the marker hides its reflected image. (*b*) A mass sufficient to elongate the spring by a readable amount is now placed on the pan (or hook), and the amount of the pull exerted by the weight of this mass is recorded (in grams-weight, or in dynes as the teacher may direct. Remember,

1 gm.-wt. = 980 dynes). The new scale reading is recorded opposite the pull that produced it. (*c*) The process of increasing the pulls, and of observing the corresponding readings is continued until ten or more sets of readings have been taken, the pulls and scale readings being tabulated in parallel columns. (*d*) After each reading, the observer removes all weight, and notes whether the pointer returns to its initial reading. If it does not so return, the load has permanently stretched the spring, and further observations are of no value.

Numerical Data.—If a spring balance graduated in grams was used, and if the weights were expressed in grams, the table of data gives the correct value in grams-force of each scale reading recorded. If a scale reading is greater than the weight that produced it by a certain amount, it is said to have a positive (+) error of that amount; and if any reading is less than the weight that produced it by a certain amount, it is said to have a negative (−) error of that amount. Look carefully at the numbers in the two columns, and see if the scale readings always increase by equal amounts when the stretching force (*i.e.* the weight) is increased by equal amounts.

Inferences.—Answer in complete sentences—(*a*) If f_1 and f_2 represent any two stretching forces, and e_1 and e_2 the corresponding elongations of the spring, do you find (neglecting small experimental errors) that
$$\frac{f_1}{f_2} = \frac{e_1}{e_2}\ ?$$

(*b*) State the numerical relation which you have found to exist (as far as your experiments go) between the elongations of the helical spring and the corresponding stretching forces. This relation is known as Hooke's Law, because it was first stated by Robert Hooke in 1678.

(*c*) Do you think that a spring balance may be used conveniently for measuring forces? Give your reasons. What advantage has a dynamometer over a set of masses for this purpose?

Sources of Error.—Briefly enumerate the sources from which you think errors may arise, and suggest any ways of avoiding them.

Exercise Number 8

GRAPHICAL REPRESENTATION. RELATION OF STRETCHING FORCE TO ELONGATION

References

Exercise Number 3. M & T 4, 5

The Purpose is to plot a graph that will show the relation between the stretching force, exerted on the helical spring of the preceding Exercise, and the resulting elongation of the spring.

Operations.—Let the abscissas represent the stretching forces, and the ordinates the corresponding elongations. The scales on which these quantities are represented should be chosen so that the graph fits the size of the page; the data for the graph should be tabulated near it; and the plotting should be done just as in Exercise 3. The parts of the dia-

gram are to be fully lettered and labeled, as before, so that it will tell its own story.

Inferences.—(*a*) If you had not already learned the relation between stretching forces and elongations from the tabulated numerical data, would this graph tell you what it is? (*b*) State the relation. How does the graph show it? (*c*) If this graph has been made from data obtained with a spring balance, explain how it may be used to find the correct value of the pull that corresponds to any given reading on the scale of the balance. A graph used in this way is called a *calibration graph*, and the process of testing the readings by comparison with known values is called *calibration.*

Note.—The elastic force with which the spring resists elongation is always equal to the stretching force, and Hooke's law is often stated in this way, "*The force of restitution is proportional to the displacement.*" The motion of such an elastic body when it is set in vibration is called *Simple Harmonic Motion.*

Exercise Number 9

PULLEYS

References

A 137–139	G E 77–79	H & W 101
C 75–77	G P 80–82	L 137–138
C & C 92, 98–100	H 93, 107–110	W & H 39, 212

M & T 33–37, 43, 76, 77, p. 95

The Purpose of the exercise is to experiment with different arrangements of pulleys in order to find

out how great a resistance can be overcome by a given force, and to determine the efficiency of a given arrangement for different loads.

The Apparatus consists of a pair of pulleys, flexible cord, a pan of known weight, and a metric rule.

Preliminary Study.—(*a*) With any arrangement of pulleys (Fig. 5), if there were no friction, how would the pull at any cross section of the cord compare with that at any other cross section?

(*b*) When a single, fixed pulley is used (*A*, Fig. 5), how should the magnitudes of two forces f_2 and f_1 compare with each other when there is equilibrium or uniform motion without friction?

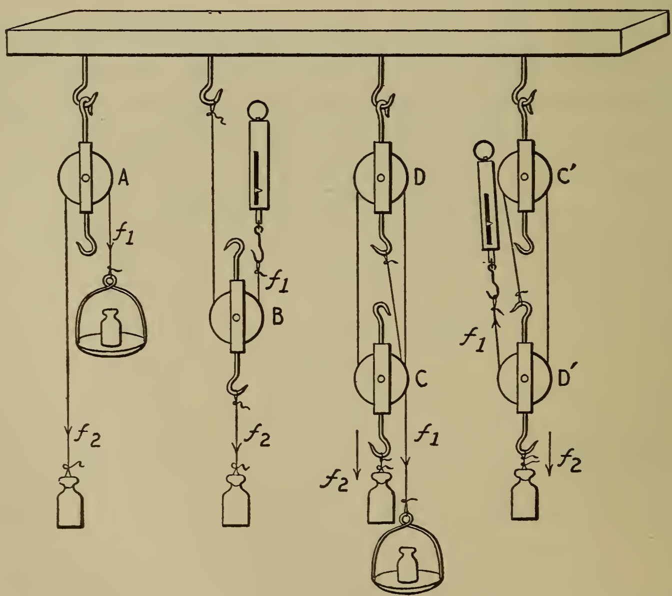

FIG. 5.

(*c*) With a single fixed pulley, is any advantage gained in applying a force, except that of changing the direction of the pull?

(*d*) With a single movable pulley (B, Fig. 5) what two parts of the cord support the movable pulley and its load? How do the upward pulls of these two parts of the cord compare with each other? How does their sum compare with the sum of the weights of the pulley and its load? Then, if the weight of the pulley, and the frictional resistance were negligible, how should the resistance f_2 compare with the effort f_1, when the number of parts of the cord supporting the movable pulley is 2?

(*e*) All other things remaining the same will the ratio of resistance to effort be changed if the free end of the cord from movable pulley C is passed over a fixed pulley D, so as to pull downward at D instead of upward at B?

(*f*) In the fourth arrangement, the pulleys C and D are changed to the positions C' and D', the arrangement having been turned end for end. How many equal forces now support the movable pulley D'? What is now the ratio of total resistance to f_1, the effort applied? This ratio is called the *mechanical advantage* of the device. How does the mechanical advantage in each of the last three arrangements compare with the number of parts of the cord that support the movable pulley?

(*g*) Test your answers by hanging on a weight for f_2 in each case, and finding what pull f_1 will balance

it, or allow it to ascend or descend with uniform speed. Is the ratio $\frac{f_2}{f_1}$ in each case nearly equal to the number of parts of the cord that support the movable pulley?

Operations.—(*a*) With the pulleys arranged as at CD or $C' D'$, Fig. 5, attach to the movable pulley a mass whose weight f_2 is greater than that of the pulley, and find by trial the number of grams-weight at f_1 (including that of the pan) that will just lift the load f_2 with uniform speed. Measure the distance l_1 through which f_1 moves while f_2 moves a distance l_2 (of, say, 10 cm.). Calculate $f_1 \times l_1$, the work in gram-centimeters done by the effort f_1, and also $f_2 \times l_2$, the corresponding work done on the resistance f_2. Calculate also the efficiency, *i.e.*

$$\frac{\text{Useful work done}}{\text{Total energy expended}} = \frac{f_2 \times l_2}{f_1 \times l_1}$$

(*b*) Now diminish the weight f_1 so it will just allow f_2 to descend with uniform speed, and calculate the amounts of work and the efficiency as before. The average of these two determinations of the efficiency is the mean efficiency for the given load.

(*c*) In the same way, find the mean efficiencies for as many other loads as the time will permit, using a considerably heavier load each time.

Data.—Tabulate all symbols and data.

(*b*) Plot a graph showing the relation between loads (taken as abscissas) and the mean efficiencies corresponding (taken as ordinates).

Inferences.—Answer in complete sentences.

(*a*) Do the data show that the efficiency of a given arrangement of pulleys increases with the load?

(*b*) Does the graph show that the efficiency increases in direct proportion to the load, or in greater proportion, or in less proportion? How?

(*c*) From the number of gram-centimeters of work, how may you calculate the number of ergs? The number of Kilogram-meters?

(*d*) In what ways have you seen pulleys used?

Errors.—What do you consider the chief sources of error in this experiment? What error is eliminated by having f_2 first ascend and then descend?

Exercise Number 10

CONCURRENT FORCES

References

A 67–72	GE 41–44, 54–56	H & W 82–83
C 57, 63	GP 42–45, 56–58	L 25, 96–106
C & C 45–47	H 47–49	M & T 44–60

Purpose. — The purpose of this experiment is to verify the principle of parallelogram of forces; that is, to compound sets of forces in accordance with this principle, and find whether the force thus determined is the true resultant.

Apparatus. — The arrangement is shown in the diagram. Three spring balances are used, to measure the forces exerted by the cords and lengths of plumber's safety chain. The chains are joined to each other and to the balances by small key rings or harness rings so that they lie perfectly flat; and the

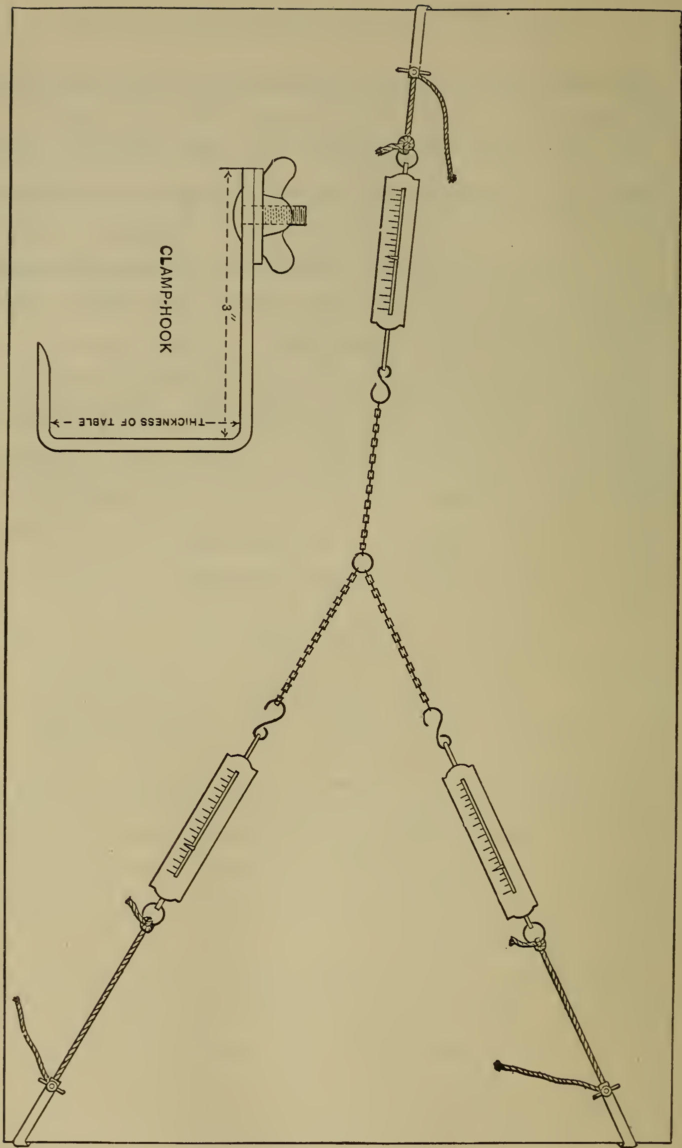

FIG. 6.—Apparatus arranged for experimenting with concurrent forces

cords are secured at any desired points at the edges of the table by clamp hooks provided with thumb nuts.

Operations. — (*a*) Let each of three students pull steadily on a balance and secure it to a clamp hook. Let the pulls be made at random, in any convenient directions and with any convenient forces, but so that equilibrium shall result.

(*b*) A note-book page is to be slipped under the chains by a fourth student, who, when the equilibrium is secured, marks on the page the positions of the chains. This he does by thrusting a pin through the links, exactly in the middle line of the chain, and pricking two points 1 1, 2 2, 3 3, for each line. The points should be as far apart as possible. *Each line is to be marked with a letter*, which will represent the force in the tabular form.

(*c*) At the same time the other three students record the readings of their respective balances.

(*d*) The positions of the corresponding lines of direction being fixed, and the lines drawn meeting at a point, record the magnitudes of the forces on their respective lines, *remembering to add the proper zero correction for each balance.*

(*e*) Let each student in turn get at least one such set of lines in his note-book; and using these lines, construct the parallelogram of the forces so recorded.

Employing any convenient scale, cut off each line proportional in length to the magnitude of the force it is to represent.

Taking any two of these lines as adjacent sides,

complete a parallelogram, and draw the diagonal from the meeting point of the three lines (point of application) to the opposite vertex. The chosen scale must be small enough so that the whole diagram will go on the page.

(*f*) To find the numerical value of the resultant, measure this diagonal and multiply its length by the number of units of force that one centimeter of its length represents. Record the resulting value on the diagram.

Zero Correction. — When used horizontally, a spring balance graduated to be used in a vertical position gives a small negative reading under no load. (Why?) This is called the zero error and its amount must be obtained as follows: Hold the balance in the vertical position, and slowly change it to the horizontal, lightly tapping it the while. (Why?)

Take off on a pair of dividers, or a straight-edged bit of paper, the length of the zero error; and apply it to the scale of the balance so as to measure its amount in scale units and tenths. Since all horizontal readings of the balance will be smaller than they ought to be by just this amount, each reading must be corrected by adding to it the amount of the zero error. The readings thus corrected give the real values of the forces observed.

Data. — Record (*a*) the scale of the diagram; (*b*) the values of all four forces (corrected balance readings in pounds and tenths, or in grams); (*c*) lengths of all four lines which represent the

forces; (*d*) name the lines representing both components, the resultant and the equilibrant, and *show their directions by arrow tips;* (*e*) record the amount and per cent of the experimental error, *i.e.* the difference between the numerical values of the equilibrant and of the resultant.

Place the data near the diagram in tabular form, as below.

Scale of the Diagram . . . .

Numerical Data

Name of Force	Force (Letters)	Balance Reading	Zero Correction	Force Amount in lbs. or gm.	Length of Line
Component					
Component					
Equilibrant					
Resultant					
Experimental error					
Per cent error					

Sources of Error. — Errors may arise from (*a*) parallax; (*b*) friction of the balances, chains, or cords; (*c*) inaccuracies in construction and measurement. Friction may be avoided by lightly tap-

ping the balances and cords to allow them to come into position in straight lines.

In constructing the parallelogram, see that the pencil is kept sharp and the dividers in good condition. Use the utmost care. If all the work is carefully done, the per cent of error will be small. To compute the *per cent* of error, multiply the error by 100 and divide by the value of the equilibrant, which may be taken as the *base*. A given error will be less important in proportion as the *base* is large. Hence use forces as large as practicable.

Inferences. — Answer, in concise sentences, the following questions: (*a*) Neglecting the experimental error, how does the resultant, as found in the experiment, compare in magnitude with the equilibrant?

(*b*) What is the direction of the resultant with reference to that of the equilibrant?

(*c*) Do you, therefore, conclude that the quantity determined in your experiment, and recorded as the resultant of the two forces that were chosen as components, is the true value of their resultant? Copy and memorize the Principle of the Parallelogram of Forces as stated below.

Principle Verified. — If two forces, acting at an angle upon the same point, be represented in direction and magnitude by two lines drawn to any given scale, then the resultant of these two forces will be completely represented, on the same scale, by the concurrent diagonal of the parallelogram constructed upon those two lines as adjacent sides.

Addition of Vectors.—Any line representing a

force, motion, or other quantity having both direction and magnitude is called a *vector*. The length of the vector shows the magnitude of the quantity, and the direction of the vector, as given by the arrow tip, shows the direction of the quantity. Since the diagonal of a parallelogram divides it into two equal triangles, and is the third side of either triangle, it may be found without constructing the whole parallelogram, as follows: Draw a vector representing either component in direction and magnitude, and from the *end* of the first vector, draw the vector representing the second component in both direction and magnitude. Then the line drawn from the *beginning* of the first vector to the *end* of the last is the vector that represents the resultant in direction and magnitude on the same scale as that by which the components are represented. This process is called the *addition of vectors. The resultant of any number of forces that act on a single point*, *may be found by adding their vectors*, *end to end*, *in any order. The resultant vector is that drawn from the beginning of the first to the end of the last;* and the equilibrant vector is that drawn from the end of the last to the beginning of the first. *If the vectors of any number of forces acting on a single point form a closed figure when added in any order*, *it may be known that this system of forces will be in equilibrium.* This method is much used by engineers, in finding the proper strengths of tie rods and struts or posts in framed structures, such as bridges, roofs and steel frames of buildings.

The student should get into the habit of looking for such sets of forces. They are found in the cases of sail boats, kites, bicycle frames, jib cranes, machinery, the poles where electric lights and trolley wires are suspended, and all kinds of structural work, such as roof trusses and bridge frames.

Exercise Number 11

WORK. INCLINED PLANE

References

A 80, 121–127, 140, 141
C 64–66, 69, 71–73, 78
C & C 48, 89–92, 101–103
GE 67, 71–73, 77, 78, 83
GP 62, 70, 74–76, 80, 86
H 53, 60–62, 94, 111
H & W 87, 97, 102
L 77–80, 93, 137
M & T 53–61
W & H 46, 199–203, 206

The Purpose of the experiment is to find out what force, applied parallel to an inclined plane, will lift a given weight, and to learn how the work done by this force compares in amount with that of lifting the weight vertically through the same height.

Apparatus. — A car, and some iron nuts or other weights, and an inclined plane, are placed as shown. A spring balance is attached to the car by a short stout cord. A metric rule and a pail or basket, or the trip scales and weights are also provided.

Operations and Data. — Holding the balance parallel to the plane, and keeping the line of sight perpendicular to the plane of the scale at the point of

reading, move the car up and down the plane, and read the amount of the force indicated while a uniform velocity is maintained. With the usual precautions, take the measurements of the quantities indicated below: —

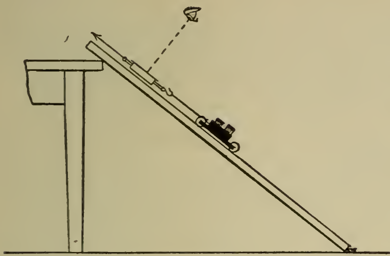

FIG. 7. — Showing how the force is applied and observed.

h, the height of the plane from floor to the point vertically above the table edge.

l, the length of the plane from *floor* to the *same point.*

z, the zero correction for the balance *in position.*

u, force required to maintain *uniform* velocity *up* the plane.

d, force required to maintain *uniform* velocity *down* the plane.

f, $\left(=\frac{u+d}{2}\right)$, the mean force required to balance the *component of weight* of car and load along the plane.

F, $(=f-z)$, the mean force as above, *corrected for zero error.*

W, the combined weight of the car and its load. This weight may be obtained directly with the trip scales, or by suspending the car and load in a pail or basket on the hook of a spring balance, the weight of the pail or basket being subtracted from the total weight in order to get the value of W.

$F \times l$, the work done *along the displacement* l, by the force F.

$W \times h$, the work done in moving the mass against the resistance W, through the vertical displacement h

e, the experimental error.

The values of h and l are to be taken in inches to the nearest $\frac{1}{8}$th, and *reduced to feet and hundredths;* balance readings in *pounds and tenths.* Or if forces are recorded in *grams*, *the distances* must be in *centimeters;* and if forces are recorded in *kilograms*, *the distances* must be in *meters.* The amounts of work will then be in foot-pounds, or gram-centimeters, or kilogram-meters respectively. If so directed by the teacher reduce the work in gm.-cm. to *ergs.* To do this multiply by 980. Why? Tabulate as here:—

DATA

Observations made by............................

u		d	
f		z	
F		W	
l		h	
$F \times l$		$W \times h$	
e		% error	

Calculations.—The amount of error is the numerical difference between $F \times l$ and $W \times h$. The percentage error is calculated by finding what per cent this difference is of the mean value of the two amounts of work.

Sources of Error. — State the sources of the errors pertaining to (*a*) the length measurements, (*b*) the balance readings, (*c*) the positions of the balances and cord in moving along the incline.

Inferences. — (*a*) Judging by your observations and the experience of the others in the class, do you think it fair to infer that the difference between the corresponding values of $W \times h$ and $F \times l$ are wholly due to experimental errors? (Why?)

(*b*) Make a complete and general but concise statement of the relation existing between the quantities of work compared.

ADDITIONAL PROBLEMS

(*Voluntary, or assigned at the option of the teacher.*)

(*a*) If you are satisfied from your experiments that the equation $Wh = Fl$ is correct (neglecting friction), find the value of the mechanical advantage $\frac{W}{F}$ of any inclined plane in terms of its dimensions l and h.

(*b*) Make the slope of the plane steeper or less steep, measure l and h, and also measure either W or F. You now have three out of the four quantities of the equation: calculate the fourth quantity. Now measure this quantity as in the experiment, and see how near its value is to that predicted by the calculation from the equation. What is your opinion as to the utility of the equation? If the slope is made less steep, can a greater weight W be lifted by a given effort F? In this case, can more work be done by it when exerted through the same distance?

(*c*) Draw a diagram of the plane, using a convenient scale for the length l and height h. Using another convenient scale for the forces, represent the weight W by a vector drawn from a point on the plane (in what direction?). Draw a vector to represent the direction of the component of the car's weight that is tending to make it travel downward along the plane.

(What should be the direction of this vector?) Does the car also push perpendicularly against the plane? How could you prove this? Represent the direction of this push also by a vector. (What direction?) Is this push also a component of the weight W? Why? Since you are not supposed to have measured the two component forces, you drew the vectors of indefinite length; and you have a side and two adjacent angles of a triangle: complete this triangle. The lengths of the two component vectors are now determined: measure each and multiply it by the scale number: what do the resulting numbers represent? Compare the value of the component F, parallel to the plane, as obtained from the vector diagram, with its value as measured by a spring balance or a weight hung from a cord and passed over a pulley. Compare the value of the push of the car against the plane as obtained by the vector method with the value of it as obtained by measuring the pull of the car against a spring balance applied so that it will just lift the car off the plane in a direction perpendicular to the plane.

(*d*) For a case of the car on the plane, measure (1) the force f_1, parallel to the plane, that will hold the car in equilibrium; (2), the weight f_2 of the car; (3), the resistance f_3 of the plane to the perpendicular push of the car. Now represent these forces by vectors drawn end to end in any order, each of the proper direction and magnitude for the force it is to stand for. Does the end of the last line meet the beginning of the first, so as to form a closed triangle? (Cf. Addition of Vectors, Exercise 10, p. 33.)

(*e*) Draw the vector diagram of the plane and forces for any case of the inclined plane where the force F is applied parallel the length l, and lifts a weight W through the corresponding vertical distance h; and prove by the geometry of similar triangles that $\frac{W}{F}=\frac{l}{h}$, hence $Wh=Fl$.

(*f*) Determine the efficiency of the inclined plane with a given slope, and for one or more loads just as was done for the pulleys in Exercise 9. What kinds of useless work are done in the case of the inclined plane?

Exercise Number 12

STRUT AND TIE. RESOLUTION OF FORCES

References

A 58	GE 56	H & W 82, 83
C 21, 57	GP 62	L 102
C & C 38, 48	H 53	M & T 44–58
	W & H 46	

Definitions.—Fig. 8 represents an arrangement of beams or posts, or rods, *p c a*, *b a*, and *b c*, exerting balanced forces at points *b*, *c*, and *a*. These beams, posts, or rods are found in all structural

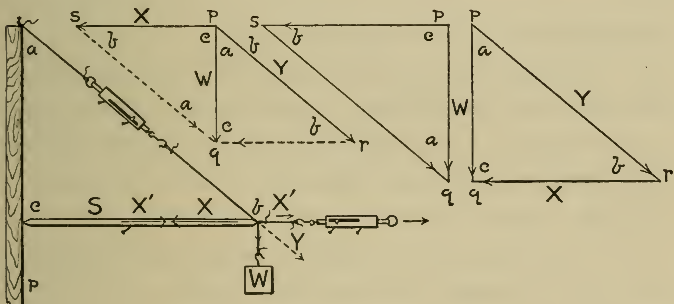

Fig. 8.

work, cranes, etc., and are called *members*. If a member has to exert a push or thrust, it is called a *strut;* and if it is under tension and has to exert a pull, it is called a *tie*. In a crane *b c* is called the boom, and post *p c a* is called the mast.

The Purpose of the experiment is to find out whether the weight *W* of the suspended mass may be conceived to be resolved at *b* into two component forces, one of which, *X*, exerts a push against the strut in the direction *b c*, and the other, *Y*, a pull on the tie in the direction *a b*.

The Apparatus consists of the post, strut, tie-cord, suspended mass and spring balances, M and N, Fig. 8. The spring balances may be supported in their positions (by resting them on pegs or wire nails driven into a large vertical board behind the apparatus) in order that their weights may not act as forces and introduce errors into the measurements. The strut is not fastened to the post, but is held by the pressure of the cord, and its weight is supported by a wire nail or peg near its middle point.

Operations.—(a) Weigh the mass.

(b) Measure each of the angles a, c, and b, with a protractor, or by placing a card behind each angle and pricking a hole with a pin at the vertex of the angle and at a point of each of its sides.

(c) On your note book page, represent W by a vector $p\ q$, drawn to a suitable scale; and complete the vector triangle for the three forces W, X, and Y. To do this, draw from p a line of indefinite length and having the direction of one of the components Y or X, and then from q another line of indefinite length, having the direction of the other component X or Y, and intersecting the vector of the first component in a point r or s. The directions may be determined by the angles. Thus the angle $q\ p\ s$ or $p\ q\ r =$ the angle c; and the angle $p\ q\ s$ or $q\ p\ r =$ the angle a. Then $p\ s$ or $r\ q$ is the vector that represents X in direction and magnitude, and $s\ q$ or $p\ r$ is the vector that represents Y. Measure the vectors for X and Y and multiply by the scale

number, to get the magnitudes of these components.

(d) Pull cautiously on the spring balance M in the direction $c\ b$ until the strut $c\ b$ just falls. The pull will then be just equal to X' the thrust of the strut, and also just equal and opposite to the component X, which X' was holding in equilibrium. (The reading of the balance should be corrected for zero error, cf. Exercise 10 p. 30.) This corrected balance reading is the magnitude of X', and also of the required component X.

(e) Read the spring balance N. Its reading (corrected for zero error, cf. Exercise 11 p. 35) is the value of the component Y and also of the equal and opposite pull Y' of the tie $b\ a$.

Numerical Data.—(a) Record on the vector diagram the lengths of the three vectors, and the magnitude of the force represented by each.

(b) In a suitable ruled form, tabulate the values of W, X, and Y obtained from the vector diagram, and also those obtained by direct measurement, so that they may be compared. Record also the zero corrections, and the amounts by which the corrected balance readings for X and Y differ from their respective values obtained by the vector method. These differences are the experimental errors, and will be smaller and smaller as more care is taken in the experiment.

(c) Indicate the directions of the weight W and the components X and Y by arrow points on the diagram.

Inferences.—Answer in complete sentences: (*a*) Are the values of the components X and Y predicted by the vector method very nearly equal to their measured values?

(*b*) What is your opinion as to the existence of the predicted components X and Y, and as to the practical value of the vector method for determining the magnitudes of such forces when they cannot be conveniently measured?

Sources of Error.—Briefly state what you consider to be the most important errors in the experiment.

OPTIONAL PROBLEM

Add in any order the vectors that represent the three balanced forces, W, X', and Y'; and see if these vectors form a closed triangle. What is your opinion as to the value of this construction in testing the calculations in structural problems similar to that in this experiment?

Exercise Number 13

LEVERS. MOMENTS

References

A 128–133	GE 47–49, 81	H & W 84, 99
C 60–62, 74	GP 49–51, 84	L 113, 137
C & C 93–95	H 96–103	M & T 62–69
	W & H 49–54	

The Purpose is to find out how great an effort must be applied to overcome a given resistance with a given lever, or how great a resistance may be overcome with a given effort, also the conditions under which a lever will be in equilibrium.

Apparatus.—A convenient lever for this purpose is a meter stick, or half of one, used as in Fig. 9.

The effort and resistance may be represented by the weights of certain masses freely suspended from any chosen points along the bar. If a pan is used to hold the masses at either point, the weight of the pan must be added to that of the mass which it supports, to get the total force applied at that point. The problem is much simplified by keeping the fulcrum (*i.e.* the axis at which the lever is supported, and about which it turns) at the middle point of the bar. By this arrangement the weight of the bar can have no moment (*i.e.* no turning effect) about the fulcrum; and so it may be neglected without introducing any error.

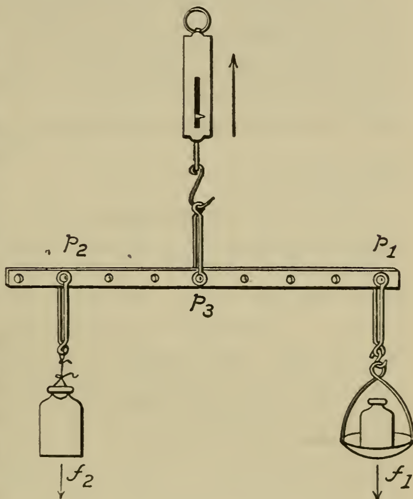

FIG. 9.

Operations.—(*a*) Suspend a known weight f_2 at p_2 having any convenient distance from the fulcrum p_3; and at some other point p_1 having a distance from p_3 greater than that of p_2, suspend just enough weight to keep the lever in equilibrium in a horizontal position. (It is not necessary to wait for the lever to come to rest; for if it swings through equal distances on opposite sides of the horizontal position it will be horizontal when it does come to rest.)

(*b*) Apply some different known weight for the effort f_1 at the same point p_1; and see what new resistance f_2 it will balance at p_2.

(*c*) Repeat the experiments, changing the arms of the forces (*i.e.* $p_3 p_1$ and $p_3 p_2$, the perpendicular distances from the axis to the lines of direction of the forces) so that the ratio $\dfrac{\text{Effort arm}}{\text{Resistance arm}}$ will be changed.

Data and Calculations.—For each experiment, calculate the moments of the effort and the resistance respectively (*i.e.* moment equals force $\times$ arm of force). Tabulate the following data in parallel columns one for each experiment,—Effort, Effort arm, Moment of effort, Resistance, Resistance arm, Moment of resistance, Experimental error. Place under the head of experimental error any differences between the numerical values of moment of effort and corresponding moment of resistance.

Inferences.—Answer in complete sentences. (*a*) Do the differences between the moments of effort and the corresponding moments of resistance approach to zero as more care is taken? Are you therefore correct in assuming these differences to be experimental errors?

(*b*) If these differences may be made so small as to be negligible, what equation may be inferred for the lever when balanced?

OPTIONAL PROBLEMS

(*a*) Repeat the experiments with the bar supported at p_3 by a spring balance or by a pan of weights attached to a

cord that passes over a pulley, and see if in each case the upward force exerted by the fulcrum at p_3 equals the sum of the two downward forces p_1 and p_2 plus the weight of the bar.

(*b*) If f_1 and f_2 are two opposing forces acting about an axis, and if a_1 and a_2 are the corresponding arms, and if it was proved by your experiments that $f_1 \times a_1 = f_2 \times a_2$, show that $\frac{f_2}{f_1} = \frac{a_1}{a_2}$. For each case, take from your table of data the values of these four quantities, compute the two ratios, expressing them decimally, and see how nearly equal they are. The ratio, $\frac{\text{Resistance}}{\text{Effort}}$, is called the *mechanical advantage* of the contrivance. May we say that the mechanical advantage of a lever is equal to the ratio of the effort arm to the resistance arm? If you know the mechanical advantage and either of the two forces, effort or resistance, show how the other may be found by a simple calculation.

(*c*) Experiment by hanging a weight that represents the resistance f_2 at the middle point (now called p_2) of the bar, and suspending the bar in a horizontal position at any two points p_1 and p_3 on opposite sides of p_2. Let p_3 now be the fulcrum or axis about which the effort f_1 of the first spring balance is to turn the bar in order to lift the weight f_2. The arm of the effort f_2 with respect to the new axis p_3 is now $p_3\ p_1$; and the arm of the resistance is $p_3\ p_2$. Measure the forces and their arms; calculate their moments with respect to p_3; and see if these moments are equal. Remember to allow for the weight of the bar by finding its effect on the balance at p_1 when there is no load at p_2 and subtracting this amount from the balance reading at p_1. Try different forces and arms and tabulate the quantities as before. Calculate the mechanical advantage for any given case; and with it compute the effort required to lift a known resistance, or the resistance that a known effort will overcome; and then test by experiment to see how nearly the calculated value agrees with that obtained by trial.

(*d*) For a given case, determine the work done by the effort and that done by the resistance, also the mean efficiencies, after the manner of the experiment with the pulleys, *p*. Repeat with the fulcrum somewhere else than at the middle of

the bar, and compare results. Is the efficiency greater when the middle part of the bar is on the effort side of the fulcrum or when it is on the resistance side? Can you explain why?

(*e*) Call the measured vertical distances through which f_2 and f_1 move (as determined in the preceding problem) l_2 and l_1 respectively. See if the mechanical advantage equals $\frac{f_2}{f_1}=\frac{a_1}{a_2}=\frac{l_1}{l_2}$. Can you prove by the geometry of similar triangles that the last two ratios should be equal if the effect of the weight of the bar were eliminated? Prove that $f_2\,l_2 = f_1\,l_1$, *i. e.* the work done on the resistance equals that done by the effort.

Exercise Number 14

WHEEL AND AXLE. MOMENTS

Note.—At the option of the teacher, a part of the class may work on this experiment while the other part works on Exercise 13.

References

A 134–136	GP 85	L 137
C & C 96, 97	H 104, 106	M & T 66, 75
GE 82	W & W 100	W & H 211

The Purpose is similar to that of Exercise 13. State it.

Apparatus.—The wheel-and-axle, Fig. 10, consists of two cylinders turning about an axis to which both are fixed. The forces are applied by cords wound round the circumferences of the wheel and the axle in opposite directions, so that one is wound up when the other is unwound. The winch, the capstan, and the pilot wheel of a boat (see dictionary) are modifications in which the effort is applied at the end of a bar or handle.

Operations.—The forces may be applied by attaching weights to the cords just as in the experiments with the lever or pulley, Exercises 13 and 9. Notice that the effort arm is the radius of the wheel and the resistance arm that of the axle, and that since the fulcrum is at their common axis, the weight of the wheel and axle has no turning effect.

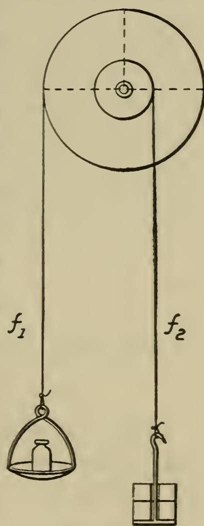

FIG. 10.

Find the efforts required to balance various resistances, and vice versa, just as directed for the lever in Exercise 13, calculate the moments, tabulate all the data, and compare results as before. As there will be some friction, determine f_2 by adding weight at f_1 until f_2 rises with uniform velocity, and then removing weight at f_1 till f_2 descends with uniform velocity. The mean effort or f_1 is the average of these two weights, and the friction force is half their difference.

Inferences.—(*a*) State whether or not the law of moments of the wheel and axle is identical with that of the lever.

(*b*) State whether the ratio of the displacements of the effort and resistance (*i.e.* the vertical distances through which they move) is equal to the ratio of their arms (*i.e.* the radii of the wheel and axle respectively). To find out, you may prove it by the geometry of the circle, or verify it by measurements in a number of cases.

OPTIONAL PROBLEMS

(*a*) Efficiency.—Determine the efficiency of the wheel and axle for given loads just as directed for pulleys in Exercise 9, and express the relation of efficiencies to loads by a graph.

(*b*) Experiments with a Dissected Clock.—1. With the aid of the printed directions in the box, assemble the clock. 2. Is the wheel and axle part of the clock motor like that of a derrick except that the clock "weight" descends and drives the gear, instead of being lifted by it? 3. Determine the lbs.-wt. of the "weight," and the distance it falls in one hour. Calculate the horsepower of the clock.

Exercise Number 15

PARALLEL FORCES AND THE LAW OF MOMENTS

References

A 69, 128–132, 134, 135	H 96–105
C 60, 63, 74–77	H & W 84, 85, 99
C & C 47, 93–97	L 53, 107-109, 113–117, 127, 137
GE 45–49, 81–83	M & T 62–70
GP 19, 46–49, 84–85	W & H 49–54

Purpose. — In this exercise it is proposed (*a*) to investigate the laws of equilibrium for three parallel forces, and (*b*) to formulate a rule for determining the point of application, direction, and magnitude of the resultant of any given pair of parallel forces.

Apparatus. — AB is half a meter stick, with wire nails passed through holes drilled at intervals along its axis, at right angles to its faces, and projecting about a half centimeter above and below; *c*, *c*, *c* are pieces of stiff wire, bent into the form of clevises. Three spring balances, with cords and clamp hooks, are used to measure the forces, F_1, F_2, F_3, in a manner similar

to that of Exercise 10. The bar is suspended by a wire, as shown, so that it hangs horizontally about a centimeter above the table.

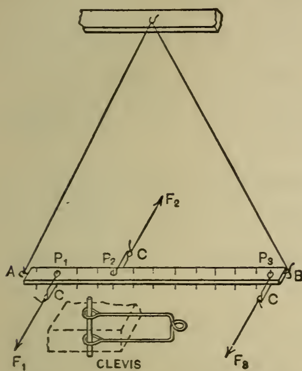

Fig. 11.—Showing how the forces are applied to the suspended bar.

Operations. — (*a*) Arrange the balances so as to exert parallel forces as indicated in the diagram. At least four cases are to be made, by varying the relative distances between the point of application, p_2, of the middle force and the points of application, p_1 and p_3, of the two end forces. These distances are varied by placing the clevises over different nails on the bar and moving the clamp hooks along the ends of the tables.

The forces may be varied in amount by drawing the cords forward or backward at the clamps and securing them by the thumb nuts when the desired tension is attained.

(*b*) Choose any convenient ratios for the distances p_1p_2 and p_2p_3, *e.g.* Case I, $\frac{1}{1}$; Case II, $\frac{1}{2}$; Case III, $\frac{1}{3}$ or $\frac{2}{3}$; Case IV, $\frac{1}{4}$ or $\frac{3}{4}$.

(*c*) *Use the utmost care* to avoid *friction* in the balances or cords, to have the forces act all *parallel* and in the *same plane*, and to see that the bar is in a horizontal position just clear of the table. Be sure that the plane of the wire that supports the weight of the bar is *exactly vertical*.

Data. — (*a*) For each case make a diagram. Represent distances and forces each on a scale appropriate to the size of the page, *e.g.* for distances, 1 cm. = 5 cm.; for forces, 1 cm. = 2 lbs., or 1 cm. = 100 g. Do not crowd more than two cases on a page.

(*b*) Above each diagram state the scale to which it is drawn.

(*c*) Underneath each diagram state what point is adopted as the centre of moments; *choose a different point* for each case, but be sure to use *that point only* throughout *that* case.

(*d*) On the line representing each force, record its value in pounds and tenths, or in grams (corrected for zero error); also *indicate its direction* by an arrow point.

(*e*) Near the line representing each arm, record its length in centimeters.

NUMERICAL DATA

FORCE (LETTER)	BALANCE READING	ZERO CORRECTION	FORCE (AMOUNT)	ARM	MOMENT
F_1					
F_2					
F_3					
		Sum		Sum	

(*f*) For each case fill out a tabular form as above. Be careful to give the dimensions of forces and arms

(lbs., g., or cm.) and the + or − signs of the forces, of the moments, and of the sums. If a force in one direction is called positive, one in the opposite direction is negative; and if a moment acting clockwise is called positive, one acting counter-clockwise is negative.

The sums are understood to be the *algebraic* sums.

Calculations. — Moment = force × arm. If the arm of any force = 0 (*i.e.* if the centre of moments is identical with the point of application of the force), the moment becomes 0. It should, however, be set down in its proper place. In solving the equation, *form the habit* of considering the moment of *each force in turn* from the left to right, *not omitting any.*

Sources of Error. — State briefly the sources of error pertaining to the different parts of the apparatus, and the operations and measurements, also the precautions necessary in order to minimize them.

Inferences. — Frame a concise statement in answer to each of the following questions: (*a*) In order that three parallel forces in the same plane may be in equilibrium, what must be the numerical value of the algebraic sum of the forces, and also of the algebraic sum of the moments about any chosen point?

(*b*) If your results show small + or − quantities for the sums of the forces or of the moments, do you think they may fairly be regarded as due to experimental errors? Why?

(*c*) Which of the conditions mentioned in (*a*) must be satisfied in order to prevent translatory motion? and which to prevent rotary motion?

(*d*) In each case, which force is the equilibrant of the other two, and how must their resultant compare with it in point of application, direction, and magnitude?

(*e*) What, then, is the direction, and what the magnitude of the resultant of any two parallel forces, compared with those of the forces?

(*f*) How does the point of application of the resultant divide the line joining those of the two forces?

Additional Work. — If there is time for extra work, the students may experiment with four or more forces in the same manner as above, or repeat the experiment with the bar not perpendicular to the lines of direction of the forces. In the latter case they should remember to measure the arm of each force on a line *perpendicular to its line of direction.*

Exercise Number 16

CENTRE OF MASS

References

A 94–95	GE 50–53	L 119, 120
C 92–97	GP 52–54	M & T 71–74
C & C 52, 54–56	H 74, 75	W & H 57, 58

Purpose. — The purpose of this exercise is to locate the centre of a mass of a pasteboard triangle, and to determine its relation to the medians.

Apparatus. — The apparatus consists of the pasteboard triangle, a pin, and a plumb-line, which may be a heavy button suspended by a thread.

Operations. — (*a*) Pass the pin through the triangle, as near as possible to one vertex, and work it around in the hole till the triangle can oscillate freely about it.

(*b*) Tie the plumb-line to the pin, and drive the latter into the wall. Adjust the thread till it is very near the triangle, but not touching it.

(*c*) Tap the triangle lightly, so that it will oscillate and then come to rest.

(*d*) By means of two fine pencil-marks locate on the triangle the position of the vertical line through the point of suspension, as indicated by the plumb-line.

(*e*) Repeat the operations for the other two vertices of the triangle.

(*f*) Draw the lines on the triangle. If the work has been accurately done, they will meet in a point.

(*g*) Test the accuracy of your work by observing whether you can balance the triangle upon a pin-point at the intersection.

(*h*) Measure and record the distances from the points in which the lines intersect the sides of the triangle to the adjacent vertices.

Data. — (*a*) Choosing a convenient scale, draw a diagram of the triangle, together with the lines mentioned in Operations (*d*) to (*f*).

(*b*) Record, either in tabular form or upon the diagram itself, the measurements of Operation (*h*).

(*c*) Record the scale of the diagram.

Sources of Error. — Make a concise statement, pointing out the sources of error.

Inferences. — Answer in brief, complete sentences, the following questions: —

(*a*) Does each of the lines drawn in Operation (*f*) contain the centre of mass? Why?

(*b*) How is the point determined? Why?

(*c*) Are the lines medians of the triangle? Why?

(*d*) What is the relation of the centre of mass to the centre of figure of any regular polygon?

(*e*) Would this be true if the polygon were not of uniform density and thickness?

(*f*) Where is the centre of mass with reference to the thickness of the triangle?

Additional Work. — If there is time for additional work, a good illustration of the practical value of this principle is to cut out to scale a pasteboard model of half a stone bridge arch, and by determining the centre of gravity of the model, locate the centre of gravity of the semi-arch.

NOTE. — This exercise may profitably be performed by the students at their homes.

EXERCISE NUMBER 17

EQUILIBRANT OF PARALLEL FORCES. EFFECT OF THE WEIGHT OF A BAR

REFERENCES

A 69, 128–132	GE 74, 78, 50, 52, 81	H & W 99
C 60, 63, 74–77 93, 94	GP 49, 50–54	L 120, 127, 137
C & C 55, 93, 94	H 51, 96–105	M & T 66–69, 71, 72
	W & H 51–54, 59a	

The Purpose of the experiment is to determine by the law of moments the direction, magnitude and point of application of the single force that will

hold a number of parallel forces in equilibrium, the weight of the bar being one of these forces.

The Apparatus consists of a bar made of a meter stick with a bent strip of lead on the end. Forces may be applied to it by hanging on it known weights by loops of thread at given points.

Operations.—(*a*) Weigh the bar. If the bar were uniform, at what point might its weight be assumed to act? It is not uniform: therefore determine its center of mass G by balancing it in a loop or clevis without adding any load. Measure and record the distances of G from the two ends.

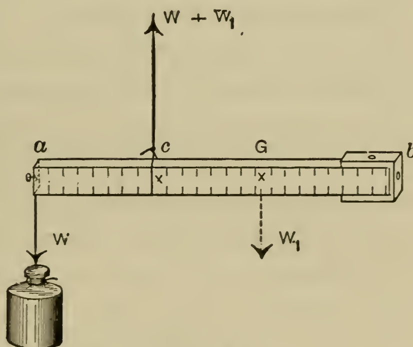

FIG. 12.

(*b*) Hang a weight W at a, and balance the bar as in Fig. 12. What should be the magnitude of the equilibrant E of the two downward forces (*i.e.* of W applied at a and the weight W_1 of the bar applied at G)?

(*c*) Measure $a\,b$. Write down the equation for the equilibrium of the moments with respect to an axis at b: thus,

$$-W \times a\,b + E \times c\,b - W_1 \times G\,b = O.$$

In this equation, all the quantities are known except $c\,b$; for E was given in the answer to the question in (*b*) above, and all the others were measured except $c\,b$. Substitute the values of the known

quantities, and solve for $c\ b$. Now measure $c\ b$ with a rule, and E with a spring balance, and see how nearly correct your calculation was.

(*d*) Make a similar case, but with one or more other weights W_2, W_3, etc. hung at any other points on the bar; and, leaving E and $c\ b$ unmeasured, put the sum of *all* the moments equal to zero as before. Calculate E and $c\ b$; then measure them, and compare calculated with measured values.

Inferences.—In calculating the magnitude and location of the equilibrant or single force which holds the others in equilibrium, you assumed that *when a system of forces is in equilibrium the algebraic sum of all the opposing forces is equal to zero*, *and the algebraic sum of all the moments about any given point is equal to zero.* Did the results predicted by the calculations fit the facts closely? If so, what is your opinion as to the truth of the principles assumed, and of their value as a basis of other calculations?

(*b*) What is your opinion as to whether or not the weight of a beam or girder in a bridge or other piece of structural work should be considered as one of the forces acting about any given point in the structure?

OPTIONAL PROBLEMS

(*a*) For either case above, take the axis at *a* or any other point except *c* or *b*, and see if your calculations, with the moments taken with respect to this new axis, give nearly the same results as before.

(*b*) Make a case with the weight W of the bar

unknown and all the other quantities measured, calculate W, then measure it and compare results.

(*c*) Make a case with G unknown, measure all the other quantities, and calculate $G\,b$ so as to find the location of G with reference to the ends of the bar. See if the unloaded bar balances at G.

(*d*) Suspend the bar at G its center of mass, hang an unknown mass at b, and move the loop by which a known weight W is suspended along the bar till it balances the weight U of the unknown mass. By the equation of moments with respect to G as in Exercise 13 with the lever, the unknown weight is $U = W \times \frac{a\,G}{G\,b}$. Calculate it, and compare with the value of U as obtained with an ordinary balance. This is the principle used in "steel-yards."

Exercise Number 18

LAWS OF THE PENDULUM

References

A 106, 112–120	GE 60–63	H & W 74–81
C 68, 87–89	GP 65–69	L 73, 141, 143
C & C 68–77	H 83–91	M & T 308, 309, 302-307
	W & H 189–193	

Part A

EFFECT OF LENGTH AND AMPLITUDE

Purpose. — The purpose of Part A is twofold: (*a*) to learn whether the period of a pendulum is

affected by the amplitude of vibration, and (*b*) to determine whether the period of a given pendulum varies directly as the square root of its length. More briefly, the aim is to verify the laws of the pendulum regarding amplitude and length.

Apparatus.—(*a*) The pendulum is made of a bullet of about 1.5 cm. diameter, into which is moulded a very small wire loop. A silk thread 120 cm. long is attached to this loop at one end, and passed into a knife slit in a cork near the other end.

(*b*) By means of a screw clamp attached to a vertical rod, the cork is firmly supported so that the thread hangs perpendicular to the face from which it emerges.

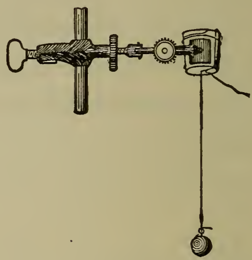

FIG. 13.—Showing how the pendulum is suspended.

(*c*) A meter stick, a rectangular block and a pair of outside calipers (cf. Appendix B, Art. 3), are needed for measuring the lengths and the diameter of the bob.

(*d*) For the time measurements a good timepiece, capable of marking seconds, is needed (*e.g.* a student's watch, a stop-watch, a metronome, or, best of all, a telegraph sounder, electrically connected with a good laboratory clock.

Operations.—(*a*) Carefully measure the diameter of the bob.

(*b*) Loosen the thumb-nut of the clamp, and draw the thread up or down through the slit in the cork, so as to make the pendulum between 25 and 50 cm. long.

Tignten the nut, wind the thread around the cork, and pass it back through the slit, so it will not slip.

(*c*) Measure accurately the distance D from the point of suspension to the bottom of the bob.

To do this, lower the clamp till the surface of the table is tangent to the bob; and set the end of the rule against the table top. Or set the rule on end next the pendulum, rest a try square (or a draftsman's triangle, or a squared block) against the rule, sliding it up or down till its upper edge is in contact with the end of the thread or with the bottom of the bob, and then read on the rule the position of the square.

(*d*) Lower the pendulum till the bob is near the table top; set it swinging over an arc not exceeding 10°, and determine the period of a single oscillation as directed in Exercise 1, p. 1.

(*e*) Without changing the length, determine the period as before for each of two different amplitudes smaller than the first.

(*f*) Make the length between 50 and 75 cm. Measure it as before, and determine the period for three different amplitudes.

(*g*) Repeat (*f*) but with length from 75 to 100 cm.

Data and Calculations. — Tabulate the observed quantities as indicated on the following page. The real length l, in any case, is the distance D (cf. Operation c) minus R, half the diameter of the bob. a represents the amplitude, o the number of oscillations made in s seconds, t the period (equal to $\frac{s}{o}$), and $\frac{t}{\sqrt{l}}$ the ratio of the period to square root of corresponding length (expressed as a decimal fraction).

Numerical Data

	Length of Arc a	Oscillations o	Number of Seconds s	Period t	Ratio $k\ \frac{t}{\sqrt{l}}$
D					
R					
l					
D					
R					
l					
D					
R					
l					

Sources of Error. — State concisely what errors may pertain to (*a*) the timepiece, (*b*) the observers, (*c*) the measurements of length.

Inferences. — In complete sentences, answer the questions below.

(*a*) Do your values of t corresponding to a given length, differ by amounts too great to be ascribed to the inevitable errors of the experiment?

(*b*) If not, when the length and place remain the

same, is the period dependent upon the length of the arc.*

(*c*) Do you consider it fair to assume that the values of $\frac{t}{\sqrt{l}}$ are all equal, or, in other words, that $\frac{t}{\sqrt{l}}$ is a constant ratio for all lengths?

(*d*) If l and l' be two lengths, and t and t' be the corresponding periods, and if $\frac{t}{\sqrt{l}} = k$ (a constant quantity), and $\frac{t'}{\sqrt{l'}} = k$ also, show that $\frac{t}{t'} = \frac{\sqrt{l}}{\sqrt{l'}}$.

(*e*) If you have answered (*b*) and (*c*) in the affirmative, state the two laws of the pendulum which you have verified by your experiments as far as they go.

PART B

ACCELERATION OF GRAVITY

Purpose. — The purpose of Part B is to calculate the mean value of g at the school laboratory from the data obtained in Part A.

Calculations. — (*a*) Put the equation of the pendulum, $t = \pi\sqrt{\frac{l}{g}}$, into the form $g = \frac{\pi^2 l}{t^2}$.

(*b*) In this formula, substitute 3.1416 for π. Substitute for l the first value of length taken from the tabulated results of Part A. Average the values of the period of oscillation belonging to this length, and

* Half the arc measures the amplitude of the oscillation, and theoretically it should not exceed 5°, but practically it will be difficult in this experiment to make it quite so small.

put the resulting quantity in place of t. Solve the equation for g.

(*c*) In like manner, substitute and calculate the value of g from each of the other lengths and its corresponding mean period.

(*d*) Tabulate and average these values of g to find the mean acceleration of gravity at your laboratory.

(*e*) If given the theoretical value of g in your latitude by your teacher, find your error by subtraction, and calculate your percentage error. To do this, multiply your error by 100 and divide by the given value of g.

OPTIONAL PROBLEMS

(*a*) PERIOD-LENGTH GRAPH.—Taking the values of l and the corresponding values of t from Exercise 18, represent the former by abscissas (scale: 1 cm. = 25 cm.) and the latter by ordinates (scale: 1 cm. = 0.1 sec.). Plot a graph. The first point of the graph (*i.e.*, $l = 0$, and $t = 0$) will be at the origin. Label the parts of the graph, and tabulate the data as directed in Exercise 3.

(*b*) MASS AND PERIOD. — Solder a pin to the bottom of a small covered lard pail (or stick it on with sealing wax, cf. Appendix H). Attach a small vise to a wooden bracket on the wall; and from the vise suspend the lard pail by a steel piano wire 2 or 3 meters long, so as to use it as a pendulum. A neater apparatus than the lard pail may be made out of a cylindrical tin box such as those in which varnish is sold. The screw top may be perforated, and the wire passed through it and soldered on the inside. Make a small pointer by sticking a knitting needle into a block of wood. After completely filling the pail with sand, put on the cover, and adjust the wire in the vise so that the point of the pin just meets the end of the pointer when the pendulum hangs at rest. Remove the pointer, and determine the period of the pendulum. Now substitute water or iron filings for the sand; readjust the length

if necessary, by means of the vise and with the aid of the pointer; and again determine the period. Since the equation for the pendulum

$$t = \pi \sqrt{\frac{l}{g}}$$

contains no expression for mass or density, and is general provided the amplitude is small, it implies that the period depends only on the length and the acceleration of gravity. Do you find that your experiments confirm this implication, *i. e.* that the period is constant for different masses and materials, provided the length and place remain constant?

CHAPTER II

FLUIDS

Exercise Number 19

DENSITY OF WATER

References

M & T 32

The Purpose is to find the mass of one cubic centimeter of water, *i.e.* the *density* of water.

The Apparatus consists of a balance and weights, a cylindrical graduate, and a centigrade thermometer.

Operations.—(*a*) Weigh accurately, a beaker or flask, containing approximately 200 cubic centimeters of pure water; pour the water into an empty graduate, being careful not to spill any, and weigh the flask again. The difference between the two weights equals the mass in grams of the water now in the graduate. Why?

(*b*) Read the volume of the water by means of the scale of cubic centimeters on the graduate. (Cf. Appendix C, Art. 2.)

(*c*) From the mass and the volume, calculate the density of the water. In the division discard all the figures beyond hundredths of a gram. With a thermometer, take the temperature of the water in centigrade degrees. On account of expansion due to the greater heat, the density of water at the tem-

perature of the room is slightly less than it would be at 0° C., its freezing temperature.

Inferences.—The true value of the density of water at 20° C. differs from one gram per cubic centimeter, but by a quantity less than half a centigram, which is less than your probable experimental errors. See how near your result comes to $1\frac{\text{gm}}{\text{cm}^3}$. Is it near enough so that you may assume in most of your work that one cubic centimeter of water has a mass of one gram?

Exercise Number 20

PRESSURE IN A LIQUID CAUSED BY ITS WEIGHT

References

A 150–152	GE 95–100	H & W 128–130
C 116–123	GP 122–128	L 157–167
C & C 123–133	H 131–142	M & T 94–105
	W & H 63–71	

The Purpose is to learn whether a liquid exerts a pressure on a surface that is submerged in it, and to find in what way the pressure is affected by the depth.

Apparatus.—A spring balance or an equal arm balance, mounted on a rod *a* that is supported by a screw clamp *s* which permits it to be raised or lowered. From the pan of the even arm balance or from the hook of the spring balance a uniform rod *r* with squared ends is suspended by a silk thread, so as to hang vertically. The rod may be of aluminum (or of wood loaded with lead at the bottom, so as to

sink upright in the water). The rod r is plainly marked with a scale of equal parts, and has a small wire loop in its upper end. A glass cylindrical graduate of say 250 cubic centimeters capacity is filled with enough distilled water so that when the rod is wholly submerged in it the water will rise nearly to the 250 cc. mark.

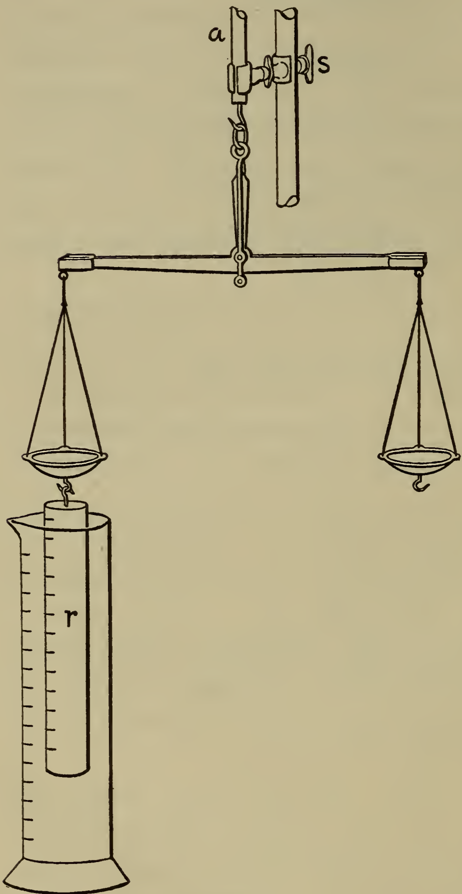

FIG. 14.

Operations. — (*a*) If the equal arm balance is used, balance the suspended rod with weights; then lower the balance till the rod will be sunk to the first of its division marks when the balance beam is horizontal. Does the water exert an upward pressure on the bottom of the rod? How is it made evident? Now remove sufficient weight from the pan to let the rod

sink till the beam remains horizontal. How does the lifting force at that depth compare with the apparent loss of weight? May this apparent loss of weight be used as a measure of the upward pressure of the water on the bottom of the rod *r*?

(*b*) Lower the balance, and remove weight till the beam is again horizontal with the rod sunk to the next division. Note the amount of weight removed, which represents the increase in the pressure of the water due to the increase in depth.

(*c*) Continue this process until the rod is entirely submerged. Does the pressure now seem to increase, or does it seem to remain constant? Do you suspect why?

(*d*) If the spring balance is used instead of the equal arm balance, each difference between the balance readings at two different depths is the apparent loss of weight and measures the increase in pressure due to the greater depth.

Numerical Data.—Record the depths and corresponding total pressures in two parallel columns.

Graphical Representation.—Represent the relation of pressures to depths by a graph, plotting the latter as abscissas and the former as ordinates.

Inferences.—(*a*) From an inspection of the data and graph, state whether the increments (increases) of pressure are equal for equal increments of depth.

(*b*) If so state the law of the relation of pressures to depths.

(*c*) When the rod was just submerged, was there

any water pressure upon its upper base? What must have been the pressure on its upper base when sunk to a distance equal to one scale division? The lower base was then one division deeper than before: why was the increased pressure on it not apparent? Why does the resultant of the upward and downward pressures remain constant at all depths after the rod is once entirely submerged?

Sources of Error.—What sources of error did you find?

OPTIONAL PROBLEMS

(*a*) Sink a Hall pressure gauge (cf. Appendix F) to different depths in a battery jar of water. At each depth in succession, turn it around a vertical axis, and also (by means of the crank) around its horizontal axis, keeping the center of the diaphragm at the same level. Watch the drop of liquid in the horizontal indicator tube, and see whether it indicates any change of pressure on the diaphragm when the latter is turned in different directions without changing the depth of its center. State the law of the relation of pressure to direction of the submerged surface when the depth remains constant.

(*b*) By means of a coupling and rubber tube, attach a small steam gauge to the water taps on different floors of the school building, record the pressures, measure the vertical distances between the levels of the taps, divide the increase of pressure between each two taps by the corresponding vertical distance, and see if the ratio of pressure to depth is a constant quantity. If so, state whether this experiment verifies the laws of liquid pressure with relation to depth and direction.

(*c*) A cubic inch of water weighs 0.0361 lbs. Calculate the number of cubic inches in columns of water each 1 sq. in. in cross section and each having an altitude equal to one of the vertical distances between two taps. Find the weights of these columns, and compare them with the increments of pressure [in lbs. per sq. in. in Problem (*b*)] to which they correspond.

Exercise Number 21

THE PRINCIPLE OF ARCHIMEDES

References

A 153	GE 113	H & W 112
C 124	GP 146	L 169–171
C & C 134–137	H 143	M & T 111, 112
	W & H 72–74	

Purpose.—It is proposed to find out how the buoyancy (lifting force) of a liquid on a body immersed in it compares in magnitude with the weight of the liquid displaced by it, *i.e.* to learn whether Archimedes' principle may be verified by experiment.

The Apparatus is that described in the preceding experiment.

Operations.—(*a*) Repeat the experiment of sinking the rod to different depths till it is entirely submerged; but at each depth take a reading of the upper surface of the water in the graduate. Each time when more of the volume of the rod is submerged, the displaced water rises to a higher mark; and the difference between the two readings measures in cubic centimeters the increase in the volume of water displaced. Since each cubic centimeter of water weighs one gram, the difference between two readings is also numerically equal to the weight of the displaced water.

Data.—Record in two parallel columns the total buoyant force at each depth, and also the corresponding weight in grams of the water displaced.

Inferences.—(*a*) State the principle of Archimedes, and say whether or not your results verify it for

water. (*b*) Do you infer that it would be true for any fluid (*i.e.* for any other liquid or any gas)?

OPTIONAL PROBLEM

Special Case of a Floating Body.—Let the floating body be a rod of wood, or let it be a large test tube ballasted with shot, and having a paper scale of centimeters and millimeters pasted inside. For this case it should be loaded with only enough ballast to make it float upright and partly out of water. Weigh the body. Proceed as before with the experiment, comparing the buoyant forces with weights of displaced water, until the buoyancy has caused the rod apparently to lose all its weight. As long as the weight of the body is greater than that of the water displaced by it, what does it tend to do? When a body has sunk till the weight of water displaced is just equal to its own weight, what does it do? Push the body downward so the weight of water displaced by it is greater than its own weight, then release it. What does it do? A concise statement of its behavior is sometimes called the *law of flotation*. State this law. Does it apply to iron floating in mercury and to a soap bubble or balloon filled with illuminating gas and floating in air? Try it. Add five grams at a time to the ballast of the floating rod, and see each time if the new weight of the floating body and the weight of displaced water are equal.

Another method of measuring the weight of the displaced water is that of having a vessel provided with a spout and filled up to the point of overflowing. When the body is placed in the vessel, the overflow is caught and weighed. This method though apparently simple, is not uniformly accurate.

Still another way of making the experiment is to suspend the filled vessel from the pan of an equal arm balance, and counterpoise it with sufficient weights. If then the floating body be lowered into it, just enough water will be displaced to leave the scales in equilibrium. This method, like the preceding, is open to the objection that sometimes the overflow is greater or less than the amount actually displaced. The error is caused by *surface tension* a phenomenon in which the surface film of a liquid acts very much like an elastic skin which has to be broken before the liquid can overflow.

Applications.—The weight of water that a ship displaces when as low in the water as it can safely be, is called its *gross displacement.* Weigh a toy boat, find its gross displacement by the overflow method, and calculate its greatest safe load. Test it with this load. Might a model be so used by a ship designer? How does an air ship, a fish, or a submarine boat rise or sink?

Exercise Number 22

RELATIVE DENSITY BY THE SUBMERSION METHOD

References

A 153, 155, 156, 160	GE 114–116	H & W 59, 112, 113
C 124	GP 146–149	L 169–176
C & C 134–136, 140–144	H 143, 146–150	M & T 32, 111–113
	W & H 72, 73, 75	

Purpose. — The purpose of this exercise is to determine (*a*) the relative density of a solid and (*b*) the relative density of a liquid with reference to water as a standard. The solid chosen is to be denser than water or the liquid, and is to be insoluble in either. Under these conditions the methods are of general application.

Part A

OF A SOLID

Apparatus. — The apparatus provided consists of balance and weights, thread, a jar or beaker of distilled water, and the solid used in Exercise 6. Diagram the apparatus as used.

Operations. — (*a*) Make a slip-noose at one end of the thread and a loop at the other end.

(*b*) Pass the loop over the hook * on the bottom of one of the scale pans, adjusting it to such a length that the solid, when suspended in the noose, will hang 10 or 15 cm. below the pan.

FIG. 15.

(*c*) Adjust the scales to equilibrium with the thread so attached.

(*d*) Suspend the solid, or place it in the pan, and obtain its weight, W.

(*e*) Suspend the solid in the jar of water, adjusting the scales so that it is totally submerged when the beam is horizontal, but touches neither the sides nor bottom of the jar; and obtain the apparent weight, W_1.

(*f*) If time permits, suspend the solid from the other pan, and obtain the values of W and W_1 as before, using their mean values, as in Exercise 6. Ordinarily the arithmetical mean will do, because it does not usually differ from the geometric mean by an amount greater than that of the unavoidable errors of experiment.

* If the balance pans have no hooks, the thread may be suspended, as shown in Fig. 15. If suspended in this way from the trip scales, the scales must be mounted on a box or other support, with the end of the balance projecting over the end of the box. The loop must be long enough so that the thread will not touch the base of the balance or any part of its support. A bit of soft wax will keep the thread in place. If the balances have the perforated horn pans, close the holes with corks and put small screw-hooks into the corks from below.

Data. — Record data in the tabular form below.

NUMERICAL DATA

Substance of the solid	
Form of the solid	
Number of the solid	
Weight, W	
Apparent weight in water, W_1	
Buoyant force, $W - W_1$	
Relative density, $\frac{W}{W - W_1}$	
Density from Exercises 6	

PART B

OF A LIQUID

Apparatus. — A jar of the liquid * whose relative density is to be determined is added to the apparatus of Part A.

Operations. — The only additional operation is that of obtaining the apparent weight of the solid while submerged in the liquid under examination.

Data. — Tabulate these as below, using the values of W and W_1 obtained in Part A.

* *E.g.* a saturated solution of common salt or of copper sulphate. Iron and lead cannot be used in the latter liquid, as it acts upon them chemically.

NUMERICAL DATA

Substance of the solid	
Form of the solid	
Number of the solid	
Weight, W	
Apparent weight in water, W_1	
Buoyant force of water on solid, $W - W_1$	
Apparent weight in liquid, W_2	
Buoyant force of liquid on solid, $W - W_2$	
Relative density of liquid, $\frac{W - W_2}{W - W_1}$	
Name of liquid	

Sources of Error. — These are as follows: (*a*) Imperfections of the balances and weights.

(*b*) Parallax in observing the pointer of the scales.

(*c*) Friction of the liquid on solid and thread, reducing the sensitiveness of the balance.

(*d*) Buoyant forces of the liquids on the thread. In very accurate work a silver or platinum wire is used, and corrections are made for the buoyant forces on it.

(*e*) Buoyant force of air on the solid. When great accuracy is sought, the corrections for deducing the weights in a vacuum are applied.

(*f*) Water may not be pure and at 4° C. Corrections for temperature may be applied.

Inferences.—(*a*) If, by definition,

$$\text{Density} = \frac{\text{Mass of the body}}{\text{Volume of the body}},$$

may the numerical value of this ratio be obtained by taking the numerical value of the expression

$$\frac{\text{Mass of the body}}{\text{Buoyant force of water on the body}}? \quad \text{Why?}$$

(*b*) If, by definition, the density of a liquid

$$= \frac{\text{Mass of the liquid}}{\text{Volume of the liquid}},$$

may the numerical value of this ratio be obtained by taking the numerical value of the expression

$$\frac{\text{Buoyant force of the liquid on a solid}}{\text{Buoyant force of water on the same solid}}? \quad \text{Why?}$$

(*c*) Is the numerical value of the relative density the same as that of the density in grams per cubic centimeter? Why?

Practical Applications.—The density of a substance is one of its most important characteristics. The knowledge of it is often indispensable, not only to the scientist, but also to the manufacturer, merchant and consumer. Find some instances.

Exercise Number 23

RELATIVE DENSITY BY THE FLOTATION METHOD

References

A 154, 157, 160	GP 150	L 172, 174, 177
C & C 138–144	H 144, 150	M & T 111, 112
GE 117	H & W 113	W & H 74, 75

Purpose. — In this exercise it is proposed (*a*) to determine the relative density of a wooden rod by applying the principle of flotation, and (*b*) to determine the relative density of a liquid by using the rod as a constant weight hydrometer.

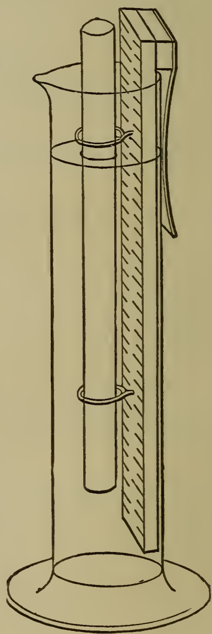

Fig. 16.— Showing the rod and support in position.

Apparatus. — (*a*) The rod of wood whose relative density is to be found must be of uniform cross-section, and should be given a thin coating of paraffin, so that it cannot absorb the water or other liquid.

(*b*) A supply of distilled water and of the liquid, each in a tall glass jar.

(*c*) A support for floating the rod upright consists of a piece of a meter rule, with two screw-eyes set horizontally into the front of it. A spring clamp attached to the back of it holds it firmly against the side of the jar.

Part A

OF A SOLID

Operations. — (*a*) Place the support vertically in the jar of water, and see that the clamp holds it firmly in position.

(*b*) Pass the rod vertically downward through both screw-eyes, and carefully allow it to sink just as far as it will. Tap very gently on the side of the jar, or support, in order to overcome any friction that may interfere with free motion of the rod upward or downward.

(*c*) Take two readings, on the support, of the position of the lower end of the rod, and the same number of readings of the upper level of the water. Wipe the rod dry, reverse it and repeat, taking four readings as before. Take the mean of the four readings for the lower end, and also the mean of the four readings for the water level. Avoid parallax by keeping the eye on a level with the point at which the reading is taken. If the surface of the water is elevated by capillary action near the rod, give the rod a fresh coat of paraffin.

(*d*) With a metric rule take four measurements of the total length of the rod.

Data. — Enter the data in a tabular form like that below. The length of the part submerged is obtained by taking the difference between the mean upper and mean lower readings. The relative density of the wood is calculated by dividing the length of the part submerged by the length of the entire rod.

NUMERICAL DATA

	READING LOWER END	READING WATER SURFACE	LENGTH OF SUBMERGED PART	LENGTH OF ENTIRE ROD
1				
2				
3				
4				
Mean				
Name of substance				
Relative density				

Theory. — Let W = weight of rod, m its mass, l its length, and V its volume; let W' = weight of water displaced by submerged part, m' its mass, v' its volume, l' its length (*i.e.* the length of the submerged part of the rod); and let D be the density of the substance of the rod, D' the density of water, and a the cross-sectional area of the rod.

Then $W = W'$ (Principle of Flotation); and since $W = m$, and $W' = m'$ (mass is numerically equal to weight when expressed in gms.-wt.),

$$m = m' \qquad \text{(Why?)}$$

Also $$m = VD \text{ and } m' = V'D';$$

$$\therefore\ VD = V'D'. \qquad \text{(Why?)}$$

But $$V = al \text{ and } V' = al'. \qquad \text{(Geometry.)}$$

Whence, by substitution,

$$alD = al'D';$$

and dividing by alD',

$$\text{Relative Density} = \frac{D}{D'} = \frac{l'}{l}.$$

Evidently this method applies to any substance less dense than water, provided it be cut of uniform cross-section, with its bases approximately perpendicular to its length.

Part B

of a liquid

Operations. — (a) Wipe the rod and support (Why?), and repeat operations (a), (b), and (c) of Part A, but with the rod floated in the liquid whose relative density is to be determined instead of in water.

In a tabular form like that on the following page enter the data thus obtained, together with the necessary datum from Part A.

(b) Calculate the relative density by *dividing the mean length of the part submerged in water* by the mean length of the *part submerged in the liquid*, in accordance with the theoretical deduction, p. 80.

NUMERICAL DATA

Trial	Reading Lower End	Reading Liquid Level	Length of Part Submerged
1			
2			
3			
4			
Mean			
Length of part submerged in water			
Relative density of liquid			
Name of liquid			

Theory. — Let W, M, V, a, and l represent, respectively, the weight, mass, volume, sectional area, and length of the displaced liquid; and let W', M', V', a, and l' represent, respectively, the same quantities for the displaced water. Also let D and D' be the densities of the liquid and of water.

Then $W = W'$ (since by the Principle of Flotation each is equal to the weight of the rod); and by reasoning precisely similar to that of Part A,

$$\frac{D}{D'} = \frac{l'}{l} = \text{Relative Density of the Liquid.}$$

Sources of Error. — Errors result from (*a*) parallax, and errors of judgment in reading (personal equation). (*b*) The rod and support may not be exactly vertical. (*c*) Slight friction may prevent the rod from floating freely. (*d*) The rod may not be exactly vertical.

Lessons. — This exercise gives valuable practice in manipulation, and in the application of the principle of flotation for the rapid determination of density where refined methods are not available. It also illustrates the principle which underlies all constant weight hydrometers.

The Principle of Flotation is fundamental in ship designing. The weight of a vessel equals its "displacement." A battleship designed to carry heavy armour and heavy guns must have a large displacement and great stability. This necessitates increased draught and breadth of beam. The naval designer must compromise between weight and speed. Compare a protected cruiser with a first-class battleship.

Additional Work. — Other woods and other liquids may be given, if desired.

Note. — If the support is not at hand, the rod may be supported laterally by the finger tips. A ring of fine silk thread may be adjusted on the rod to mark the upper level of the liquid, and the length of the part that was submerged measured by a rule. Paraffining the rod and support serves the additional purpose of preventing the liquid from adhering to them, and thus disturbing the true level of the liquid. It is desirable to use the same liquid that was chosen for Exercise 22, so that the results by the two methods may be compared, and a check on their accuracy thus secured.

Exercise Number 24

RELATIVE DENSITY OF A LIQUID BY HARE'S METHOD

References

A 165, 166	GP 131, 144, 149	M & T 97–100
C 131–133	H pg. 139, 159–161	
C & C 146–148	H & W 121, 153	
GE 102–104	L 182	

Purpose. — The purpose of this exercise is to determine the relative density of a liquid by the method of balancing columns supported by atmospheric pressure.

Apparatus. — The apparatus consists of two glass tubes, each nearly a meter long, and joined by rubber tubing to the two branches of a three-way tube (made from a T-tube bent as shown); and to it is attached a long rubber tube terminating in a glass mouthpiece. The glass tubes are secured to a meter stick by rubber bands, and the meter stick is fastened in a vertical position by screw clamps (or by any convenient support). Its end rests on the table-top. The ends of the glass tubes should terminate in short rubber tubes which dip into two beakers or small jars, one containing distilled water, and the other the liquid whose relative density is to be determined.*

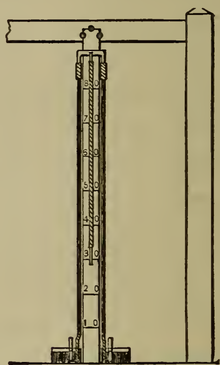

Fig. 17.— Apparatus for the determination of relative density by Hare's method.

* Use the same liquid as in Exercises 22 and 23.

A pinch-cock, or a Hoffman screw-compressor, is placed above the mouthpiece on the rubber tube, to prevent the ingress of air after it has been withdrawn.

Operations. — (*a*) Remove, rinse, and replace the mouthpiece.

(*b*) Open the pinch-cock, remove air from the tubes until the columns of liquid stand a little below their upper ends.

(Why do the liquids rise to unequal heights? Which liquid is the denser?) The air is to be removed by suction at the mouthpiece a little at a time, so as never to allow the liquids to be pushed over the bend. (Why?) In case such an accident should occur, remove the entire apparatus to the sink and rinse it thoroughly. The columns can be held at any desired point, while the pinch-cock is being adjusted, by closing the end of the mouthpiece *with the tongue.*

(*c*) After closing the pinch-cock, watch the apparatus for a moment, to see that it does not leak, then read on the rule the positions of the upper ends of the columns. Read to tenths of millimeters, being careful to avoid parallax. In like manner read the position of the liquid surface in each of the beakers. Make each upper and each lower reading from the bottom of the meniscus. In reading, it is convenient to hold a straight-edged card against the scale and tube, with its upper edge parallel to the divisions of the rule. The two lower readings should be taken as nearly as possible at the same instant, and so also should the two upper readings.

(*d*) Let the liquid columns run down a few centimeters, and repeat the observations. Take as many sets of readings as time permits. Remember that

the longer the columns, the less is the percentage error. In order to eliminate the small error due to capillary action, it is well to have a short piece of tubing, like that of the apparatus, placed in each beaker, and to take each lower reading at the bottom of the meniscus in the short tube. This tube should be held vertically, and not too near the long tube or to the side of the beaker.

(*e*) Remove the pinch-cock after completing the readings.

Data and Calculations. — Record the *name* of the liquid, the readings, and the derived data in a tabular form like that below. The height of each column is obtained by subtracting the smaller reading from the greater. The relative density for each set of readings is obtained by *dividing the height of the water column* by the height of the *liquid column*. Compute the mean relative density from the numbers in the last column, and record it below the data, together with the values of the relative density of the same liquid obtained in Exercises 22 and 23.

Numerical Data

Water			Liquid			
Lower Reading	Upper Reading	Height of Column	Lower Reading	Upper Reading	Height of Column	Relative Density

Theory. — Let m, v, a, h, and D represent respectively the mass, volume, sectional area, and height of the liquid column; and let m', v', a, h', and D' represent the same quantities for the water column.

Then since they are balanced by the same resultant atmospheric pressure, the weights and therefore the masses of the two columns are equal, *i.e.* $m = m'$.

But $$m = vD = ahD$$

and $$m' = v'D' = ah'D'. \qquad \text{(Why?)}$$

$$\therefore ahD = ah'D'; \qquad \text{(Why?)}$$

and $$hD = h'D'. \qquad \text{(Why?)}$$

Whence $$\frac{D}{D'} = \frac{h'}{h} = \text{Relative Density.} \qquad \text{(Why?)}$$

Sources of Error. — (*a*) Errors may arise from temperature changes. In very accurate work corrections must be applied for expansion; or the columns must be cooled to 4° C.

(*b*) Dirt in the tubes may affect the amount of capillary elevation or depression.

(*c*) There will also be errors due to parallax and personal equation.

Lesson. — Besides useful laboratory practice this exercise affords valuable practice in applying the principles of fluid equilibrium.

Exercise Number 25

CALIBRATION AND USE OF A LACTOMETER

References

A 154, 160, 161	GE 113–117	H & W 112–116
C 121–124	GP 146–151	L 169–172, 177–178
C & C 138, 139, 144	H 143–150	M & T 112
	W & H 72–75	

The Purpose is to graduate a glass tube so as to use it for determining the density of any given liquid such as milk, and to see how density indicates the purity.

The Apparatus consists of a deep glass jar and a "blank" hydrometer-tube. This is a slender glass tube, open at the upper end, and having two bulbs blown in it,—one at the lower end, and the other a few centimeters above the first. A Bunsen burner, a paper millimeter scale, balance and weights, distilled water, salt, some mercury or fine shot, and a bit of sealing wax are also provided.

Construction.—(*a*) First insert cautiously some mercury from a small paper funnel, or some shot, as ballast till the tube floats upright in a jar of distilled water, and is submerged to within two or three cm. of the upper end of the tube. With a long wire push a bit of cotton into the neck of the bulb to act as a stopper.

(*b*) Trim the millimeter scale till its width is a little less than the inner circumference of the tube; then roll the scale sidewise round a small glass rod or tube so as to make of it a cylinder; and slip it, zero end up, into the tube.

(*c*) Again float the tube in the water; and with a stiff wire move the scale up or down until the zero coincides with the water level. Test it carefully to see if it is right, then fasten it in place by means of a tiny bit of sealing wax (which you can melt with a hot wire). After floating the tube again to see if the zero is correct, the open end may be fused in the Bunsen flame and closed with a pair of pincers, —care being taken not to remove any of the glass. Why?

Calibration.—(*a*) Thoroughly dissolve 2.50 gm. of salt in 250 cu. cm. of distilled water, thus making a solution of brine having a density of 1.01. Immerse the tube in this solution, and take the scale reading to which it sinks.

(*b*) Add another 2.5 gm. of salt to the water, stir till thoroughly dissolved, and again immerse the tube and take the reading.

(*c*) Continue this process until no more salt will dissolve in the water. If it is desired to carry the calibration further, barium chloride or lead acetate (Caution! They are both poisons) may be used, as these substances are much denser than salt, and therefore denser solutions may be obtained with them.

Calibration Graph.—Plot a graph using the scale readings as abscissas, and representing the corresponding densities by ordinates on any convenient scale.

Density of an Unknown Solution.—The teacher may have prepared several samples of brine (called

A, *B*, *C*, etc.), whose densities are known to him but unknown to the members of the class. (*a*) Place the instrument, which will now be called a *hydrometer*, into one of these solutions; take the scale reading and from the calibration graph determine the density of the solution. (*b*) To do this, find the point on the axis of abscissas that corresponds to the observed scale reading, and erect there a perpendicular cutting the graph, at a point which may be designated by the letter of the solution tested. (*c*) Measure the length of this perpendicular from the axis of abscissas to the point of the graph. This distance multiplied by the number of grams per cubic centimeter that one cm. represents on the axis of ordinates is the density of solution in $\frac{\text{gm}}{\text{cm}^3}$.

Lessons.—(*a*) State why the hydrometer rises in a solution denser than water. (*b*) State how you would calibrate a hydrometer to be used for liquids less dense than water.

The Sources of Error are, changes in temperature of the water or solution, and errors in reading the scale. The scale should be read as accurately as possible,—to five-tenths of a millimeter at least. Avoid parallax.

OPTIONAL PROBLEM

Milk Test.—A hydrometer used for testing the density of milk is called a lactometer. (*a*) Bring from home a sample of your milkman's milk. Stir the cream into the milk, and test the density of the sample with your hydrometer, as you did that of the salt solution. It should be between 1.030 and

1.033. (*b*) Think out how the density of milk would be changed by watering it, then water a part of it and see if your prediction is verified. (*c*) Since the cream is buoyed up by the milk so that it floats to the top, do you infer that it is more dense or less dense than skim milk? Should the milk be more dense or less dense when the cream is stirred into it than it is when the cream has been separated from it? Test a sample of the milk from which the cream has been skimmed, and compare its density with that of the unskimmed milk. State whether or not your conclusion is verified by the test. Dishonest milkmen sometimes skim their milk, and then add water till the gain in density due to the removal of the cream is offset by the loss due to the dilution with water. This fraud may be detected by determining the percentage of cream in a sample of the milk, and this will be found too small.

In the Babcock Cream Test, a sample of the milk is placed with sulphuric acid in measured proportions in a specially graduated flask. Considerable heat is generated by the chemical action which results; and all the other constituents are separated chemically from the cream. The cream, however, still remains mechanically mixed with them. The flask is then placed with four others in a whirling apparatus, and rapidly revolved (with their bottoms outward toward the circumference of the circle of revolution) for several minutes. On account of its smaller density the cream is pushed inward toward the center of the circle of revolution by the denser milk residues and so collects in the long graduated neck of the flask, while the other constituents press outward toward the circumference, *i.e.* toward the bottom of the flask (cf. M. & T. Art. 89-91). When the flask is removed from the separator the amount of cream can be read off in the graduated neck of the flask.

Besides the heat of combination of sulphuric acid and water, this test shows the effect of centrifugal force with rotation, for the cups in which the flasks are held hang vertically at first, but stand out horizontally when rotated. It also demonstrates the necessity of balancing the moments of mass (cf. M & T, Art. 89-93); for there must be either two or four flasks placed symmetrically in order that they may rotate smoothly.

Exercise Number 26

CONSTRUCTION AND USE OF PUMPS

References

A 172–175	GE 109, 111	H & W 142-147
C 135	GP 144, 145	L 182
C & C 159–160	H 171, 177	M & T 94–99, 101, 102, 110
	W& H 84–87	

Construction.—The parts of a model pump, Fig. 18, may be made by the student or teacher at prac-

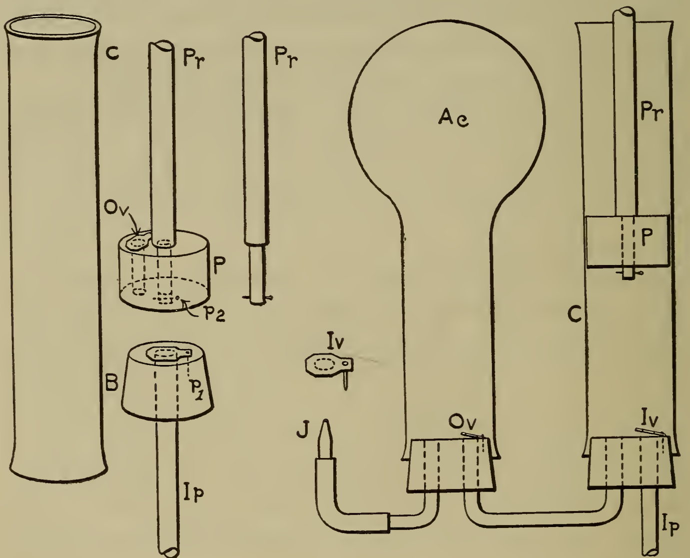

Fig. 18.

tically no cost. The cylinder C is made by cutting off squarely the end of a broken test tube (cf. Appendix F). This end is thickened in a Bunsen flame, and made flaring, like the other, to receive the bottom B. B is a cork, perforated to receive a piece of glass tubing Ip about 15 cm. long. Ip

represents the inlet pipe. The inner end of the inlet pipe is covered by the inlet valve $I v$ cut from a piece of dentist's sheet rubber, and stuck on with a short pin, p_1. The piston P is a cork, filed to a cylindrical form so as to fit C snugly, but not tightly enough to stick. It is perforated to receive the piston rod $P r$. This rod is keyed into the cork by a pin or a peg, p_2. Another perforation is covered by the outlet valve $O v$, made and mounted just as $I v$ is.

Operation.—Observations.—Answer the questions by clear concise sentences, so as to make a description of the action of the pump and of its theory. Make a diagram *from the apparatus itself*, and refer to it in your description. *Do not use the word suction.*

(*a*) Assemble the parts as shown, place the bottom B firmly in the lower end of the cylinder C and push the piston P into the upper end of C. Place the end of the inlet pipe $I p$ in a battery jar of water.

(*b*) Push down the piston rod $P r$, and watch the valve $O v$. Probably you cannot see it lift. Prime your pump by pouring in a very little water at the top. Now work the piston up and down. Which valve opens, and which one closes during the down stroke? What pressure closes the one and opens the other? Of what two pressures is this pressure the resultant? What becomes of the air that was in the cylinder during the first down stroke? During the next up stroke? What becomes of the air in the inlet pipe during the first up stroke? What

finally happens to all the air that was in the cylinder and inlet pipe?

(*c*) Continue raising and lowering the piston. Watch the valves and the incoming and outgoing water at each stroke. What resultant pressure closes the inlet valve and opens the outlet valve on the down stroke? What resultant pressure keeps the outlet valve closed during the up stroke? What resultant pressure opens the inlet valve at the same time?

(*d*) How does priming a pump cause it to work better?

(*e*) Read the barometer (cf. Appendix E), so as to find how high a column of mercury the atmosphere is supporting; and remembering that the density of mercury is 13.6 $\frac{gm}{cm^3}$, while that of water is 1 $\frac{gm}{cm^3}$, calculate how high a column of water the atmospheric pressure would support in the inlet pipe of a pump, provided the pump did not leak. Suppose that the inlet pipe were longer than this and you worked the pump: what would happen? Why?

OPTIONAL PROBLEMS

(*a*) Suction.—The word suction means a *process*, not a *force*, and is a convenient word when so used; but ignorant people often talk glibly of a "force of suction," and about "drawing" or "pulling" water or air out of places, thinking they are explaining something. Make the following experiment, and then say whether there is any such thing as a force of suction. Remove the piston from the pump; and leaving the inlet pipe in the water withdraw the air from the cylinder by the process of suction with the mouth. Note that in doing so you simply enlarge the mouth cavity, thus reducing the air

pressure in it and the cylinder. Do you thus exert on the water a force of suction which pulls or draws it up? Or is the water simply pushed up by something else? By what? Now place your finger over the lower end of the inlet pipe, so this push from without cannot be exerted on the water within the pipe; and suck again at the mouth of the cylinder. Can you pull the water up? Is there a force of suction?

(*b*) A Force Pump may easily be made similar to the lift pump. In this, the piston P is solid; and the lower cork B_1 has two holes, one fitted with the inlet pipe and inlet valve, and the other fitted with a U shaped outlet tube Ot (cf. Fig. 18). This outlet tube passes from below through the cork of an inverted flask Ac which will serve as an air chamber. The outlet valve Ov_2 is placed over the end of the outlet tube inside the air chamber. Through the cork of the air chamber another glass tube is passed to which is attached a piece of rubber tubing and a small glass jet, representing a hose and nozzle. *Operation*: work the force pump, watch the motion of the valves and liquid, and also of the air in the air chamber. May the description of the action and theory of the lift pump be applied to explain the force pump, with very slight changes? What changes if any? What is the use of the air chamber, which may be seen on almost all force pumps?

(*c*) The Siphon.—Fill a rubber tube about 18 inches long with water, close the ends with your fingers, and invert it with one end in a jar A of water and the other in an empty jar B at a slightly lower level. Remove the fingers. Does the water flow from the higher jar into the lower? When the lower jar is about half full raise it till the water levels are the same in both jars. Does the water flow now? Raise B till the water in it is at a higher level than that in A. Which way does the water go? Determine the rate of flow, *i.e.* measure the number of $cm.^3$ that flow out in a certain time and divide the former by the latter.

Increase the difference of evel between the water surfaces in the two jars, so as to make the long arm of the siphon still longer. What is the effect on the rate of flow? With the help of Problem 13, and Fig. 80, Mann & Twiss's *Physics*, p. 135, state briefly the behavior of the siphon under the conditions just mentioned, and explain why it so acts.

Exercise Number 27

BOYLE'S LAW

Part A. — Verification

References

A 168, 169	GP 131, 137	M & T 114, 115
C 136–142	H 166–168	W & H 79–81
C & C 161–163	H & W 124, 125	
GE 107	L 189–190	

Purpose. — The purpose of this exercise is to determine the relation between the volume of a given mass of gas, at constant temperature, and the pressure under which it is confined; or, more briefly, it is to verify the law of Boyle.

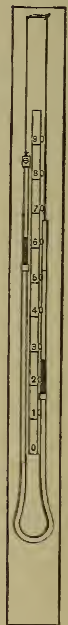

Fig. 19. — Apparatus for verifying Boyle's Law.

Apparatus. — (*a*) A glass tube about 30 cm. long, closed at one end by a capping disk and clamp screw, is joined by about a meter of rubber gas tubing to another glass tube of the same bore, open at both ends and about 50 cm. long. This composite tube is mounted on a board so that the two sections of glass tubing are vertical, and can slide up and down on opposite sides of a meter rule. They are suspended by a cord, sliding over screw hooks at the top of the board, and can be held in position by stiff rubber bands. The apparatus contains as much mercury as will fill it to the middle points of

the two glass sections when these points are at the same level.

This adjustment should be made by the teacher (or, if by a student, under the eye of the teacher) as follows: (1) Set the tubes so that the middle points of the glass sections are at the same level. (2) Turn the clamp screw backward, and loosen the capping disk so as to allow free passage of air under it. (3) Pour mercury through a funnel into the open section till it stands at the middle points of the two glass sections. (4) Adjust the capping disk, and force it down by the clamp screw till it closes the tube air-tight. The board is secured to the table in an upright position by screws, or by clamping in a vice or carpenter's hand-screw.

(*b*) A mercurial, or aneroid barometer, and a thermometer are provided.

Operations. — (*a*) Note the temperature of the air near the apparatus. It should be kept constant throughout the experiment.

(*b*) Adjust the open tube at the greatest convenient height, and the closed tube at the least. Read and record the following: (1) The height of the barometer, B, in cm.; (2) the level, s, of the mercury in the open tube; (3) the level, s', of the mercury in the closed tube; (4) the level, e, of the upper end of the air column inside the closed tube. Read from the *middle* of the meniscus, estimating, if practicable, to the hundredth of a centimeter.

(*c*) Lower the open tube and raise the closed tube each a few centimeters, and take a new set of four readings as before.

(*d*) Continue the process until the open tube is at the lowest convenient point, and the closed tube at the highest. Obtain one set with the mercury at the same level in both tubes.

Data and Calculations. — Let a represent the internal sectional area of the glass tubing, l $(= e - s')$, the length of the column of confined air, and h $(= s - s'$, positive or negative), the difference of level between the two mercury surfaces.

(*a*) Record in tabular form, making a column for the different values of each of the following quantities: s, s', e, l, h, B, $B + h$, $(B + h) \times l$.

(*b*) State whether the values of $(B + h) \times l$ are equal within the limits of experimental errors for all values of $B + h$ and the corresponding values of l; *i.e.* is the product $(B + h) \times l$ a constant?

If the sectional areas of the tubes are uniform, the volume V of the confined air varies as l, and the total pressure is $P = B + h$. (For P equals the weight per sq. cm. of the mercury column l, plus the weight per sq. cm. of the atmosphere on the mercury in the open tube; and this atmospheric pressure is measured by B.)

Therefore if $(B + h) \times l$ is found to be constant, VP must be constant. Hence we may write for a given mass of gas at constant temperature,

$$- VP = K \text{ (K being some constant)},$$

$$\text{or } VP = V' P',$$

$$\text{or, } \frac{V}{V'} = \frac{P'}{P}.$$

Inference. — (a) Write a general verbal statement of the meaning of the equation, $VP = K$, and also of the meaning of the equation, $\frac{V}{V'} = \frac{P'}{P}$.

(b) Do your results verify these two statements?

Sources of Error. — These are: (a) Any cause tending to change the temperature of the confined air or mercury. Hence, avoid letting the hands, the breath, or sunshine come into contact with them.

(b) Parallax.

(c) Air or other impurities mixed with the mercury.

(d) Leakage, inward or outward, changing the mass of confined air. This will not occur if the capping disk is tight and the rubber tube is securely wired and cemented to the glass tubes.

PART B. OPTIONAL PROBLEM

Pressure-Volume Graph.—Represent observed values of l by abscissas, and corresponding values of $B + h$ by ordinates.

Since the values of $B + h$ are rather large in proportion to the amounts by which they differ from one another, it is well before plotting to subtract from each ordinate an even amount (say 50 cm.) somewhat less than the smallest observed value of $B + h$; or in other words to let the base line of the graph represent $B + h = 50$ cm. instead of the axis of abscissas, which represents $B + h = 0$.

This leaves the lower ends of all the ordinates off the page, but does not cut off any points of the graph that represent observed values of $B + h$. If this is done a larger scale can be used, say for $B + h$ 1 cm. = 5 cm. and for l (if the left ends of the abscissas are also left off), 1 cm. = 1 cm.

From the changes of slope of the graph infer the limit of V when P approaches (1) zero, and (2) infinity.

CHAPTER III

HEAT

Exercise Number 28

CHANGES OF TEMPERATURE AND OF STATE

References

A 216–221, 235, 240
C 131–133, 220–223, 229–232, 243–245
C & C 305–315, 331, 337
GE 126–128, 145, 149, 150
GP 206–214, 239, 248, 262
H 235–245, 272, 274, 277, 286
H & W 121, 167, 168, 177, 184, 186, 187
J 1–9, 12, 41–43, 47, 50–54, 56
M & T, 116-137
W & H 90, 94, 99, 102, 104

The Purpose is to study some of the phenomena of melting and boiling.

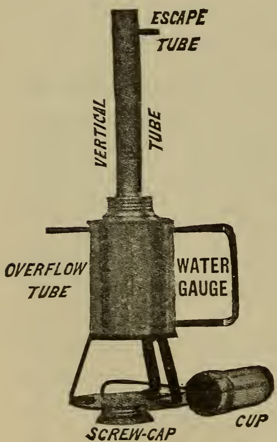

Fig. 20—The Boiler.

The Apparatus consists of a centigrade thermometer, a tin cup (or a beaker), a boiler Fig. 20, a Bunsen burner, and a U-shaped open mercury gauge, Fig. 21.

Operations.— Observations. — (*a*) Nearly fill the tin cup with cracked ice and fill the interstices between the lumps of ice with cold water. Make a hole for the thermometer with a pointed stick, and push it cautiously into the hole till it is submerged up to the zero mark. Watch the mercury. Does it

descend? Stir the ice and water frequently with the stick, being careful not to break the thermometer. After a time do you find that the mercury becomes stationary? If so, take the reading to tenths of a degree. While reading the thermometer allow only the upper end of the mercury column to emerge from the water. Prefix the positive (+) sign if this reading is above zero or the negative (−) sign if it is below zero. This reading is the *zero error* of the thermometer, and must be subtracted *algebraically* from any reading of this thermometer in order to get the correct temperature with it.

In reading avoid parallax by keeping the line of light perpendicular to the scale at the point of reading. The divisions will look straight when read from the correct position, but will appear convex downward or upward if the eye is too high or too low.

(*b*) Place the cup on a retort ring (over asbestos or a sand bath if the beaker is used). Turn on the gas and ignite it by holding the lighted match at least four inches above the burner. *If the flame "strikes back" and burns in the tube, turn off the gas and relight it.*

Now place the lighted burner under the cup, and stir the mixture of ice and water continuously, watching the thermometer till the ice is all melted. Does the temperature remain constant during this time? This constant temperature is called the melting point of ice. Do butter, paraffin, beeswax, lead, etc., have the same melting point as ice?

(*c*) Watch the thermometer after the ice has

melted. Does the temperature change? Does it rise steadily with the steady addition of heat, or does it change suddenly?

(*d*) Transfer the water to the boiler, screw on the tall vertical tube, close the overflow tube (but not the escape tube) with a wooden plug. Attach a T-shaped wire stop to the ring in the thermometer, and pass the thermometer through a snugly fitting cork which is to be placed in the end of the vertical tube. The thermometer will now hang in the water vapor, and will register its temperature. Watch the thermometer until the water is heard to boil and a steady cloud of condensed steam is seen at the escape pipe. What you *see* consists not of steam but of water in minute globules. Is steam visible? (Look at the space between cloud and the opening of the escape pipe.) You may put your fingers into the cloud at some distance from the opening; but *you will get badly burnt* if you do not keep them out of the invisible jet of steam.

(*e*) Can you increase the temperature of the steam by a more rapid supply of heat so long as the steam is escaping freely?

(*f*) If you are satisfied that the temperature remains constant, read the barometer, and then read the thermometer to the tenth of a degree, allowing only the upper end to emerge from the hole in the cork. Record the reading of the thermometer as the boiling point of water *at the observed atmospheric pressure, and according to the thermometer you are using.*

(*g*) Remove the plug from the overflow tube and attach the mercury gauge (Fig. 21) by means of a rubber tube. Does the mercury remain at the same level in both arms of the gauge? If so, how does the pressure of water vapor at the boiling point compare with the surrounding (*i.e.* the atmospheric) pressure?

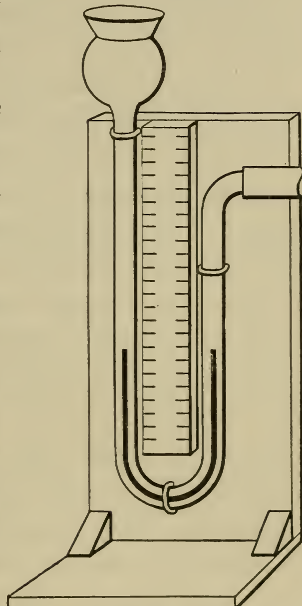

Fig. 21.

(*h*) Turn down the gas, close the escape pipe by means of a rubber tube and pinch cock, then cautiously increase the heat if necessary, thus causing both the temperature and the pressure of the vapor to rise. Take readings of several temperatures and corresponding pressures. The pressures are read in millimeters of mercury by observing the number of mm. by which the mercury column on the air side of the gauge exceeds that on the vapor side. This excess added to the barometric reading gives the total pressure on the confined vapor (cf. Exercise 27 p. 96). Does an increase in the surrounding pressure raise the boiling point? Why should it do so?

(*i*) Turn off the gas and watch the changes of pressure as the temperature falls. Watch particularly for the point when the *total* pressure equals

760 millimeters. Your thermometer, *if correctly graduated*, will then read 100°. Is it correct? If so, record the fact; if not, record the amount of the error.

(*j*) After a time the temperature of the vapor will have fallen two or three degrees below 100°, and *if the boiler and connections are air tight*, the excess of mercury will be on the vapor side of the gauge. Does this mean that the vapor pressure is less than that of the atmosphere? Is the vapor pressure then equal to the barometric pressure *minus* this excess? Why? Does a decrease in the pressure cause a lowering of the boiling point? Why should it?

Numerical Data.—Record the observed numerical quantities in a neatly devised tabular form.

Lessons.—The questions in the preceding section are intended to guide the student in his observations and thought. He is expected to write under this heading in the fewest words possible a clear description of the observed phenomena.

OPTIONAL PROBLEMS

(*a*) Boiling Point Error.—Careful observations of the change of boiling point of water due to changes of pressure show that the boiling point increases 1° C. for every 27 mm. increase of pressure, or 0.037° per mm. How do your observations compare with this statement? Then, if we wish to calculate the boiling point $t°$ as indicated by a *correct* thermometer at any barometric pressure B, we may do so by adding to 100° 0.037° for every millimeter by which the observed barometer reading exceeds 760 mm. (standard pressure), or subtracting from 100° 0.037° for every millimeter by which it is less than 760 mm. [In symbols $t° = 100° + 0.037\ (B - 760)$.]

Let the student calculate the true value of the boiling point at the observed atmospheric pressure, find the boiling point error, by subtracting algebraically the true boiling point at the observed pressure from that indicated by his thermometer and record this error with the other data and the number on the label of the thermometer.

A thermometer whose errors amount to more than half a degree will not give respectable results in the experiments on specific heat and latent heat.

(*b*) MELTING POINT OF TALLOW OR BEESWAX.—Heat a glass tube in the Bunsen flame, rotating it in the fingers till soft, withdraw it from the flame and quickly pull it lengthwise, making a thin tube. Break off a piece of this capillary tube about 6 cm. long. Melt some tallow or beeswax and suck up some of it into the tube, avoiding the admission of air bubbles. Fasten this tube to a thermometer with a small rubber band. Place them in a cup or beaker of water and heat the water, stirring it meanwhile. When the substance begins to melt, it becomes transparent. When this occurs, observe the temperature. Now let the water cool, and when the substance solidifies and becomes opaque, take the temperature again. The mean of these two temperatures is the melting point of the substance. Is the melting point of a substance practically the same as its freezing point?

(*c*) DETERMINE THE BOILING POINT OF ALCOHOL or ether by placing some in a test tube with a thermometer and heating it in a bath of water till it boils steadily. *Keep the test tube slightly inclined.*

(*d*) BOILING POINT BY THE VAPOR PRESSURE METHOD.—Bend a glass tube into a J shape, the arms being about 10 and 20 cm. long. Fill the tube with mercury to 5 cm. above the bend. Place a few drops of alcohol or ether in the short arm, tilt it till the mercury reaches nearly to the upper end of short arm, and cautiously seal off the short end with a blow pipe. (It should be nearly closed off before putting in the liquids. The tubes had better be filled beforehand by the teacher unless the students have been previously taught how to do it.) Place this tube in a vessel of water, heat and stir the water till the mercury takes the same level in both branches, then read the thermometer. When it does so, how does the vapor pressure

compare with the surrounding (atmospheric) pressure? Record the observed temperature, which is the boiling point of the substance.

(*e*) Effect of Dissolved Salts on boiling point. Place a thermometer in the boiler and take the temperature of the steam while the water is boiling. Then open the top and throw in a teaspoonful of salt. Does the boiling stop? Repeat the observation of the steam temperature, increasing the heat if necessary. Does the addition of a substance in solution raise the boiling point?

(*f*) Effect of Surface of Containing Vessel.—Boil water in a glass beaker, previously cleaned with acid and then with soap suds and distilled water. Boil distilled water in the beaker and take its temperature. Let the water cool a little and then drop in a few chips of copper or brass, renew the heating and again take the temperature. Does the boiling point depend on the nature of the surface of the vessel in which it is boiled?

(*g*) Effect of Pressure on the Melting Point of Ice.—Slowly squeeze a rectangular piece of ice in a vise or a letter press. Does melting go on much more rapidly than it did before? Does the work done in squeezing the ice help the heat energy to melt it? What facts can you cite to prove that ice expands when it freezes and contracts when it melts? Can you explain why substances that contract when they melt have their melting points lowered by pressure?

Exercise Number 29

DEW POINT AND RELATIVE HUMIDITY

References

A 239	GP 255–256	J 59–67
C & C 341	H 276	M & T 132–134
GE 157	H & W 190–192	W & H 126–130

The Purpose is to find the temperature at which the water vapor will condense from the atmosphere of the laboratory (*i.e.* the dew-point), and to calcu-

late the relative humidity (*i.e.* how near the moisture in the room space is to the pressure of saturation).

The Apparatus is very simple, consisting merely of a brightly polished nickel-plated cup, a thermometer, some water and some snow or chips of ice.

Operations.—(*a*) Partly fill the cup with water, which should be at or slightly above the temperature of the room. See that the outside of the cup is bright and perfectly free from all spots or tarnish. (Breathe on it, and polish with flannel or chamois skin if necessary.) Add snow or chips of ice, a very little at a time, with constant stirring, watching attentively for the first formation of dew on the bright outside surface of the cup below the water line. It will be recognized by a dimness in contrast with the polished surface where the dew has not yet begun to form. Take the temperature when the dew first begins to appear. *Be careful not to breathe on the cup*. Why?

In winter the dew point is likely to be below 0° C. In case the dew does not appear on the cup when its temperature has reached 0° pour off the water and stir in salt with the ice.

(*b*) Having cooled the cup a little below the temperature of the dew point, wipe off the dew and begin to add warm water, a very little at a time, stirring constantly until the thin coating of dew which will have formed on the outside has just disappeared; then take the temperature. Theoretically this should be the same as that at which dew began to deposit, but practically the first temperature will probably be a little lower than the dew point, and the second a

little higher. Hence the mean of the two readings will be nearer the true value than either of them.

(*c*) Having observed and recorded the dew point, read and record the temperature of the air, turn to the table, Pressures of Saturated Water Vapor (Appendix G) and take from it the pressure of saturated water vapor corresponding to the temperature of the air when your experiment was made. Take also the vapor pressure corresponding to the temperature that was the dew point at the same time. Find what percent the latter is of the former. This ratio or percentage is the *Relative humidity*, i.e. *it is the ratio of the pressure of the vapor in the room to the pressure which would be exerted by the vapor if in sufficient quantity to saturate the room at the observed temperature*, and it tells how nearly saturated the room space is.

Lessons.—Answer in complete sentences: (*a*) Do you and your classmates exhale water vapor? If you do not know, breathe on any cold bright surface and look at it for evidence. Also remember the cloud which issues from your mouth or nostrils on a very cold day. Should you find the relative humidity of the school room higher after it has been occupied for some time, than before? Compare relative humidities determined in the room at different times during the laboratory period or day.

(*b*) With a given amount of moisture in the room will the relative humidity be higher or lower as the temperature is raised? Why does artificially heated air feel so dry? What is the remedy?

(*c*) Will the dew point of a room be raised or lowered by boiling water in it? What effect will this have on the relative humidity?

(*d*) Other things remaining the same, what effect does cooling the air have on its relative humidity? What happens when the out-door air is cooled till its relative humidity is 100 per cent,—first, when the temperature is above 0° C. (or 32° Fah.); second, when it is already below 0° C.?

(*e*) What difference in conditions determines whether water vapor in the air shall be deposited as dew or as frost?

OPTIONAL PROBLEMS

(*a*) Determine the dew point and relative humidity in your home with a silver or tin cup or even an ordinary drinking glass and an ordinary thermometer. (If the thermometer has a tin case you can slide it out of the case. You will have to convert each Fahrenheit reading to Centigrade in order to use the vapor pressure table. To do this, subtract 32° and multiply by $^5/_9$.) Compare the result with the relative humidity taken out of doors. If there is a difference, account for it. Physicians state that the relative humidity for best indoor conditions should be kept as high as 50 per cent. If you find that of your home lower, examine your furnace (if the house is thus heated) and see if there is a pan in the hot air jacket designed to hold water to be evaporated into the air that is conveyed into the rooms. If there is such a pan *see to it that it is kept filled.* If there is no such provision have water exposed in open vessels near the registers, radiators, or grates.

(*b*) Make a determination of the dew point and relative humidity out of doors and compare it with that made by the weather observer at the same time. (If you live in a city where a weather station is located and it is not published in the daily papers you can get it from the observer by telephone.)

Exercise Number 30

SPECIFIC HEAT

References

A 225–226, 309–311, 242, 247	H 281–283, 253, 254, 258, 262
C 246–248, 224–226, 229–232	H & W 205–210, 197–199, 202
C & C 325–328, 343–347, 350, 351	M & T 125, 126, 138–140, 147–152
GE 130–135, 158, 159, 163	W & H 107–109, 121–123, 125
GP 219–224, 257, 382	

Purpose. — In this experiment the specific heat of a metal is to be determined by the method of mixtures.

Apparatus. — This consists of the following: —

(*a*) Balance, weights, and pincers.

(*b*) The boiler of Exercise 28, with the cup which fits into the boiler in place of the cover.

(*c*) A Bunsen burner.

(*d*) A calorimeter, consisting of a cup of thin brass, nickel plated, supported upon a cork in a jar or box, and packed around with cotton-batting or felt.

(*e*) Perforated wooden covers for the cup and calorimeter.

(*f*) Two thermometers.

Materials. — The substance whose specific heat is to be determined, may be in the form of punchings or short clippings of wire or a loose roll of the sheet metal. A supply of cold water should also be at hand.

Operations. — (*a*) Half fill the boiler with water and place the Bunsen flame under it.

(*b*) See that the metal has been thoroughly dried, either on top of a radiator, or in a drying oven, and

weigh it to .1 g. If the metal is in loose form, it may be weighed in the calorimeter.

(*c*) Transfer the metal to the cup, insert the latter in the boiler, put on the cover, and *cautiously* thrust the thermometer through the perforation into the midst of the metal.

(*d*) Weigh the calorimeter; place in it the amount of water specified by the instructor; and, having dried the outside, weigh it to .1 g. Place a thermometer in the water, stirring it occasionally.

(*e*) When the temperature of the metal has become stationary, see that everything is in readiness for quickly transferring the heated metal to the calorimeter. It is best to have the boiler at the right hand, the calorimeter at the left.

(*f*) Now read the temperature of the water and the metal to .1°, as nearly as possible at the same moment.

(*g*) *Immediately* after these temperatures are taken remove the thermometers, slightly tilt the calorimeter toward the cup with the left hand, carry the cup, with the right hand, toward the calorimeter, and empty the metal into it, by quickly inverting the cup over the calorimeter. Instantly cover the calorimeter; insert its thermometer through the perforated cover; and cautiously stir the metal and water together by means of the thermometer, watching the mercury column attentively.

(*h*) When the temperature has reached its highest point, if ascending, or its lowest if descending, record its reading to .1° as the temperature of the mixture.

(*i*) Dry the calorimeter and return the metal.

Remarks. Calculations. — (*a*) Great care should be taken not to spill any of the metal or water after it has been weighed. (Why?)

(*b*) In this exercise two students may work together, dividing operations so as to save time, especially at critical moments. Thus the first may read the temperature of the metal and transfer it to the calorimeter, the second taking the temperature of the water, and so on throughout. The division of labor should be planned before beginning the experiment.

(*c*) The mass of the water is obtained by subtracting that of the calorimeter from that of the calorimeter and water; and that of the metal is obtained in a similar manner.

(*d*) The relative amounts of metal and water should be so chosen as to have the mixture come as nearly as possible to the temperature of the room. Thus the errors due to radiation and conduction will be nearly eliminated. (Why?)

To secure the best results, the water should be ten degrees or more below the temperature of the room; and the relative masses, so chosen that the mass of the water multiplied by the difference between its temperature and that of the room equals the mass of the metal multiplied by the difference between its temperature and that of the room, multiplied by its specific heat. The teacher may well make a preliminary experiment and calculation, and roughly indicate the amounts of metal and water. The actual amounts will necessarily depend on the size of the calorimeter and the kind of metal used. For a calorimeter of about 350 cc. capacity, 300 g. of copper and 100 g. of water are approximately the right proportions.

(*e*) If the water is not cool enough to give a suitable temperature range (at least 10°), it should be kept cool by a bit of ice. *No unmelted ice should remain in the calorimeter, however, at the time of mixing.*

(*f*) If but one thermometer is available, the temperature of the metal must be taken when it has become stationary, and the thermometer transferred to the water in order to get the temperature of the water and calorimeter.

Data. — Tabulate the quantities as indicated below

Name of metal		
Temperature of metal	t_m	° C
Temperature of mixture	t	
Temperature range of metal	$t_m - t$	
Mass of metal and calorimeter		g
Mass of calorimeter	M_c	
Mass of metal	M_m	
Amount of heat given out by metal	$S_m \times M_m \times (t_m - t)$	calories
Temperature of mixture	t	° C
Temperature of water	t_w	
Temperature range of water	$t - t_w$	
Mass of water and calorimeter		g
Mass of calorimeter		
Mass of water	M_w	
Amount of heat absorbed by water	$1 \times M_w \times (t - t_w)$	calories
Temperature of mixture	t	° C
Temperature of calorimeter	$t_c \ (= t_w)$	
Temperature range of calorimeter	$t - t_c$	
Mass of calorimeter	M_c	g
Amount of heat absorbed by calorimeter	$\frac{1}{2} \times .09 \times M_c \times (t - t_c)$	calories
Specific heat of the metal	$S_m =$	

Heat Equation. — Equate the total amount of heat given out by the metal with the total amount absorbed by the water and calorimeter. (Why?)

S_m is the only unknown quantity. Solve the equation and find it.

Sources of Error. — (*a*) Those involved in the temperature readings are most important, an error of .1° in a range of 10° amounting to 1%. Hence the temperature range of the water should be made as large as practicable. (How?)

(*b*) Errors also occur in mass determination, and from losses or gains of heat by radiation and conduction.

(*c*) Since the calorimeter does not wholly come into contact with the mixture, only part of it is subject to the entire temperature range. If less than half filled it is fair to assume that half its mass changes temperature; and the error involved in this assumption is small, because its thermal capacity is relatively small. If a larger portion is filled, a correspondingly larger fraction should be assumed.

(*d*) Any loss of time in mixing, after reading the temperatures, and any loss of metal or water by spilling causes errors. (Why?)

Lessons. — Practice is given in the determination of an important physical constant, and in the use of the requisite apparatus, and in handling the equations pertaining to the transference of heat units when temperature changes take place.

Applications.—Try to explain the enormous effects of the large specific heat of water on climate.

Exercise Number 31

LATENT HEAT OF FUSION

References

A 244, 245 *a*	GE 145–148	J 43
C 249	GP 239, 243	M & T 135–137, 138–140, 147–152
C & C 329–333	H 284	
	H & W 211, 219, 220	W & H 112, 114

Purpose. — The latent heat of fusion of ice is to be determined.

Apparatus. — The boiler, calorimeter, scales, weights, pincers, and two thermometers are needed.

Materials. — The materials used are cracked ice, or snow, and water.

Operations. — (*a*) Place a thermometer in the calorimeter, and, after a while, note its temperature.

(*b*) Thoroughly cleanse the boiler, if necessary; half fill it with water and heat it.

(*c*) Weigh the calorimeter.

(*d*) When the water is nearly at the boiling point, pour into a beaker as much as will fill about two-thirds of the calorimeter, and determine the mass of the beaker and water.

(*e*) Meantime, have ready on a cloth or blotting-paper, in the coolest place available, about as much cracked ice as, when melted, will fill one-third of the calorimeter. It is to be kept as dry as possible till used.

(*f*) When the water has cooled to about 70° C., take its temperature to the tenth of a degree, and

immediately pour into the calorimeter the ice, and then as much of the warm water as will nearly fill it. Instantly, put on the perforated cover, insert a thermometer, and with it keep stirring the mixture until the ice is melted. *Stir gently, so as not to break the thermometer.*

(*g*) Watch the mercury, which will become stationary for a moment just as the ice disappears; at this moment read and record the temperature of the mixture.

(*h*) Weigh the calorimeter and its contents; also weigh the beaker with any water that may have remained in it.

Calculations. — To get the mass of the water used, subtract the mass of the beaker and water remaining in it from the mass of the beaker and water before pouring.

To get the mass of the ice, add the mass of the water to that of the calorimeter, and subtract this sum from the combined mass of the calorimeter and its total contents.

The temperatures should be read as accurately as possible to the tenth of a degree.

The weighings are more than sufficiently accurate if made to the tenth of a gram. (Why?)

Data. — Tabulate the observations as indicated on the following page. The factor .09 in the quantity of heat gained or lost by the calorimeter is the specific heat of the brass of which the calorimeter is made.

Temperature of water	t_w	°
Temperature of mixture	t	°
Temp. range of water	$t_w - t$	°
Mass of beaker and water		g.
Mass of emptied beaker		g.
Mass of water	M_w	g.
Heat given out by water	$1 \times M_w \times (t_w - t)$	calories
Temp. of calorimeter	t_c	°
Temperature of mixture	t	°
Temp. range of calorimeter	$\left\{\begin{array}{c} t_c - t \\ \text{or} \\ t - t_c \end{array}\right.$	°
Mass of calorimeter	M_c	g.
Heat $\left\{\begin{array}{c}\text{lost} \\ \text{or} \\ \text{gained}\end{array}\right\}$ by calorimeter	$\left\{\begin{array}{c} .09 \times M_c \times (t_c - t) \\ \text{or} \\ .09 \times M_c \times (t - t_c) \end{array}\right.$	calories
Mass of calorimeter and total contents		g.
Mass of calorimeter and water	$M_c + M_w$	g.
Mass of ice	M_i	g.
Heat absorbed by ice in melting	$L_i \times M_i$	calories
Heat absorbed by melted ice in warming to $t°$	$1 \times M_i \times (t - o)$	calories
Latent heat of ice	L_i (calories per gram)	

Heat Equation. — Equate the total quantity of heat absorbed with the total quantity given out. (Why?) Solve for L_i, the latent heat of ice, which is the only unknown quantity.

If the calorimeter changes temperature, the quantity of heat lost or gained by it should be properly placed in the equation; thus, if its temperature was *higher* than that of the mixture, the calorimeter *lost* heat, and the amount lost should be added to that *lost by the water*.

Sources of Error. — (*a*) State the kinds of errors to which this experiment is liable in common with the preceding one.

(*b*) What additional error may arise from wetness of the ice?

(*c*) If the ice or snow is collected from out doors when the atmospheric temperature is considerably below freezing, what source of error is present? How may this further error be corrected or eliminated?

Lessons. — The exercise affords practice in the manipulations of heat measurement, and in the principles and methods employed in solving problems pertaining to heat transferences when the latent heat of melting is involved.

Applications. — Large quantities of heat must be transformed into molecular potential energy in order that ice may be melted. The reverse transformation occurs whenever water freezes. Try to explain in detail the applications of these facts to refrigerators and ice-cream freezers, and to the prevention of sudden changes of temperature in the vicinity of lakes. Try also to think out how the first fact operates to reduce the severity of spring freshets in ice-bound streams.

Exercise Number 32

LATENT HEAT OF VAPORIZATION

References

A 246	GP 250	H & W 213, 218
C 250	GE 149–151	J 54–55
C & C 335, 342	H 285, 286	M & T 135–137, 138–140, 147–152

Purpose. — It is proposed to determine the latent heat of vaporization of water.

Apparatus. — (*a*) The boiler used in the last three exercises is to be furnished with a water-trap and delivery tube, as shown, and 18 inches of rubber gas tubing for connecting them with the boiler. All should be tightly fitted, so that steam can escape from the boiler only through the end of the delivery tube.

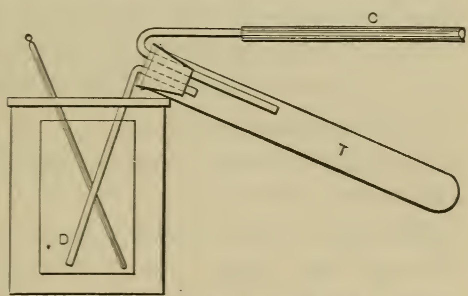

Fig. 22. — Calorimeter, cover, and water-trap: *D*, delivery tube; *T*, water-trap; *C*, rubber tube leading from boiler.

(*b*) A thick band of paper, or a wooden tube holder, is necessary for handling the hot apparatus.

(*c*) Two thermometers, balance, weights, and pincers are to be near at hand.

Operations. — (*a*) Half fill the boiler with water, generate steam, and take its temperature as in Exercise 28.

(*b*) Remove the thermometer, and lay it in a safe and convenient place. With the holder, remove the tall tubular cover from the boiler, and screw on the flat cap.*

(*c*) See that the trap and delivery tube are emptied of water, and connect them with the outlet tube of the boiler.

(*d*) Weigh the calorimeter, and having added about 200 cc. of water, weigh again. These weighings should be made while waiting for the water to boil.

(*e*) Take the temperature of the water, which should be at least 10° below that of the room. (If necessary, cool it with bits of ice before weighing. *No ice, however, should remain unmelted at the time of recording the temperature.*)

(*f*) *Immediately* after taking the temperature of the water, introduce the delivery pipe through the perforated cover, and allow steam to pass vigorously through the water. A thermometer (better previously warmed in the hand to about 10° above the temperature of the room) should be inserted through a second hole in the cover.

(*g*) Move the delivery tube about in the water, but do not place it so far below the surface that you cannot plainly hear the rattling of the collapsing steam bubbles.

(*h*) When the temperature of the mixture is as *far above* that of the room *as the water temperature*

* If the conical topped form is used, the openings should be closed with stoppers.

was below it, withdraw the delivery tube, and as soon as the temperature ceases to rise with continued stirring, record it.

(*i*) Weigh the calorimeter with its contents, and from the three weights now recorded deduce the mass of the original water and also that of the condensed steam.

(*j*) If time permits, read the barometer and attached thermometer; correct the barometer reading for temperature as in Exercise 28, and calculate the temperature of the steam by *adding* to 100° .037° for every millimeter by which the barometer column stands *above* 760 mm., or *subtracting* .037° for every millimeter by which the barometer column stands *below* 760 mm. The boiling point thus calculated is likely to be more nearly correct than that taken by the thermometer.

Data. — Enter all the observations as soon as they are taken, in a ruled tabular form like that on the next page.

Heat Equation. — Equate the sum of the quantities of heat absorbed by the water and the calorimeter, with the sum of the quantities given out by the steam in condensing and by the resulting water in cooling to $t°$; and solve for L_s, the latent heat of steam, which is the only unknown quantity.

Sources of Error. — (*a*) State those pertaining to each kind of observation, and to radiation and conduction. Explain how they are provided against by the methods adopted.

(*b*) Against what very important error does the water trap provide?

NUMERICAL DATA

Temperature of the water	t_w	° C.
Temperature of the mixture	t	° C.
Temperature range of water	$t - t_w$	° C.
Mass of calorimeter and water		g.
Mass of calorimeter		g.
Mass of water	M_w	g.
Quantity of heat absorbed by water	$1 \times M_w \times (t - t_w)$	calories
Quantity of heat absorbed by calorimeter	$.09 \times M_c \times (t - t_w) \times \frac{1}{2}$	calories
Mass of calorimeter, water, and condensed steam		g.
Mass of calorimeter and water		g.
Mass of condensed steam	M_s	g.
Quantity of heat yielded by steam while condensing	$L_s \times M_s$	calories
Temperature of the steam, *i.e.* boiling point	t_s	° C.
Temperature range of condensed steam	$t_s - t$	° C.
Quantity of heat yielded by condensed steam in cooling	$1 \times (t_s - t) \times M_s$	calories
Latent heat of steam	L_s	calories per gram

Lessons.— These are similar to those derived from the two preceding exercises. The student should state them concisely.

What fundamental principle of Physics is assumed in the heat equations of Exercises 30, 31 and 32?

Practical Applications.—Try to think out the applications of the high latent heat of vaporization of water and other liquids in the following cases: steam-heating apparatus, effect of evaporation and condensation in modifying atmospheric temperature, prevention of too rapid evaporation and condensation of moisture in nature, severity of burns caused by steam, loss of energy in a non-condensing steam engine, porous water-coolers, cooling effect of bay rum, relief from excessive bodily heat by perspiration and fanning, ice-machines, solidification of liquefied gases by their own evaporation, the production of extreme low temperatures by the evaporation of liquid air.

CHAPTER IV

MAGNETISM AND ELECTRICITY

Exercise Number 33

LINES OF MAGNETIC FORCE

References

A 365–369	GE 337–343	H & W 221–226
C 256–268	GP 486–494	W & H 240–251
C & C 358–377	H 291–301	JJ 68–87

M & T 199–206, p. 242, Sug. 1

Purpose. — The purpose of this exercise is to determine the positions and directions of the lines of force in the magnetic fields of bar-magnets.

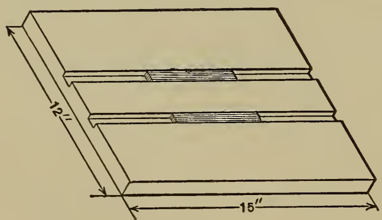

Fig. 23.

Apparatus. — This consists of two bar-magnets, a box of fine iron filings, a sifter, a small compass, a board with grooves as shown, and a square of window-glass or glazed paper of the same size as the board. The sifter is either a square of fine wire gauze with its edges bent up, or a little bag of muslin.

Part A

Operations and Observations. — (*a*) Place a magnet in one of the grooves and near the centre of the board. The flat surface of the magnet should not project above that of the board. Lay the glass or paper over the magnet and fasten it down with bits of soft wax or with thumb-tacks.

(*b*) Determine the poles of the magnet. The north-seeking pole is that which repels the north-seeking pole of the compass-needle. (Why?)

(*c*) Place some filings in the sifter, and by gently tapping it with a pencil sift the finest iron dust through it upon the glass (or paper), distributing them evenly, but *not too thickly*, all over the space around the magnet.

(*d*) Tap the board very lightly with the pencil or a ruler, using *vertical* blows only, and striking at different points successively until the filings have come into their positions of equilibrium in response to the resultant magnetic forces acting upon them in their respective parts of the field.

(*e*) Now, upon the note-book page make a diagram of the magnet and the filings. The copy of the outlines of the magnet, and of the curves into which the filings have settled in all parts of the field, should be as faithful as you can make it. If not of the same size, the proportions should be carefully preserved. Letter the poles *N* and *S*.

(*f*) Place the compass, successively, near each corner of the magnet, and also opposite the middle

of each end and of each side; at each of these points observe the position into which the needle settles; and at the corresponding position on the diagram draw a short arrow with its point in the position of the north-seeking pole of the needle.

(*g*) Remembering that the *lines represented* by the filings are *not broken*, but *continuous*, draw several of these *full* lines on each side of the axis of the magnet. Note that they are *closed curves* (but not circles or ellipses), each one passing out of the north-seeking pole of the magnet and around on the outside toward the south-seeking pole, then through the body of the magnet to the point where you began to trace it. Note also that the curves are bisymmetrical with respect to the axis of the magnet.

(*h*) Over the diagram write the heading, Field of a Single Bar Magnet; and under it write, "Each line of force represents at any point the direction which a free north-seeking pole would take at that point in consequence of the resultant magnetic force."

PART B

(*a*) Arrange the magnets as shown in either diagram (Figure 21), and repeat all the operations, again drawing arrows at the characteristic points of the field.

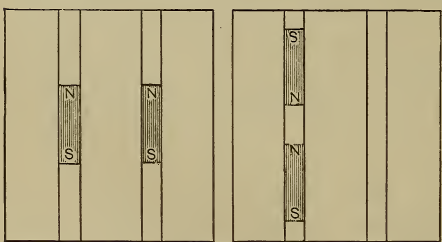

FIG. 24.

(*b*) Above the

diagram write the heading, Field of Two Bar Magnets, Side by Side (or End to End), Like Poles Adjacent; and below the diagram state what the lines represent, as before.

Part C

(*a*) Place the magnets as in one of the diagrams of Figure 21, — the one not chosen in Part B, — but reverse one of the magnets so that unlike poles shall be adjacent.

(*b*) Make all observations and records as in the preceding cases.

Inferences and Lessons. — (*a*) Is the magnetic field confined to the plane of the board, or does it include all planes? How can this be proved?

(*b*) In each case, where is the strength of field the greatest?

(*c*) Show by small diagrams the arrangement of the lines of force between two poles that are repelling each other and between two poles that are attracting each other, and label them appropriately.

(*d*) In investigating magnetic properties and their consequences it is very important to know definitely the directions of the lines of force and the relative strengths of different parts of the field.

Additional Work. — If there is time (*a*) place a small rectangle of soft sheet-iron between the two poles in the arrangements of Parts B and C, and sketch the field, stating concisely what changes in the paths of the lines are due to the *permeability* of the soft iron.

(*b*) Map the lines about a bar magnet pole in a plane perpendicular to the axis of the magnet.

(*c*) Map the field of a horseshoe magnet lying flat and also with poles up.

(*d*) Very pretty results may be obtained by mapping the field of three or more magnets arranged in a triangle, square, pentagon, cross, etc.

Permanent Maps. — If the student does something in photography, he will find it very fascinating to repeat these experiments in a dark room, using a photographic plate instead of the glass or paper. Make the map by ruby light on a slow or medium plate, exposing to the light of a match at one or two feet distance, then developing and fixing in the ordinary way. Developing or printing-out papers also give excellent results. In all cases carefully avoid over-exposure.

Another method is to coat a sheet of ordinary glass with shellac varnish; dry it; make the map; and then warm it on a sand-bath over a stove until the shellac softens and the filings sink into it.

Maps made on glass, when backed with ground or opal glass and bound or framed for transparencies, will make pretty ornaments.

Pieces of watchspring, straightened and magnetized, make excellent magnets for all these experiments, and cost nothing.

Exercise Number 34

FIELD OF ELECTROMAGNETIC FORCE

References

A 375, 377, 381	GE 349–354, 308, 309	H & W 252
C 269, 270, 291, 315, 317–319	GP 445, 507–514	JJ 119–126
C & C 452–459	H 371–376	M & T 207–
T 195–204, 389, 390, 393	W & H 278, 281–284	214,226–228

Purpose. — It is proposed to investigate the magnetic field about a current-bearing conductor.

(*a*) When straight. (*b*) When in a single loop. (*c*) When in a helix. (*d*) When in a flat coil. (*e*) When the helix or coil is associated with a soft iron core.

Apparatus. — The apparatus and its arrangement are shown in the diagram. A drawing made from the objects themselves should be placed in the note-

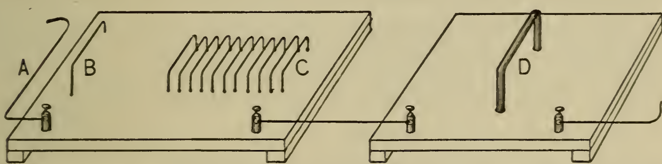

FIG. 25. — Conductors arranged so that their fields of electromagnetic force can be mapped.

book. Iron filings, sifter, and compass are provided as in Exercise 33; also a square and a rectangle of soft sheet-iron.

Operations and Observations. — (*a*) Dip the bare wire, *A*, into the box of filings, and make a sketch of what you see.

(*b*) Sift filings over the two boards, tap the boards till the filings find their places, disconnect the current and sketch the fields about *B*, *C*, and *D*. *If you are using the dynamo current in series with other tables, do not disconnect.* The teacher will attend to that.

(*c*) Place the compass in the characteristic parts of each field, *B*, *C*, *D*, and draw *thin* arrows in corresponding positions in your diagrams just as in Exercise 33.

(*d*) Place the rectangular strip of sheet iron lengthwise in the helix, *C*, but not touching it, and similarly place the square in the flat circular coil, *D*, repeat operations (*b*) and (*c*), making new diagrams, or stating each effect in words, as preferred.

(*e*) The direction of the current will be given you by the teacher. Indicate it by *short*, *thick* arrows in all parts of the circuit and especially near the coils.

(*f*) Do not crowd the diagrams, nor make them too small. It is better to put only one drawing on a page. Label the fields, Straight Wire, Helix, etc.

Inferences and Lessons. — Make clear, concise sentences answering the questions below.

(*a*) What is the form of a line of force about *A* or *B*?

(*b*) Looking along the wire in each case *with* the direction of the current, do the lines of force go clockwise or counter-clockwise?

(*c*) What is the direction of the lines of force if the current is coming *toward* you?

(*d*) Is the field of *C* what it should be if the lines of force are the resultants of the lines of force of several loops like the single one *B*?

(*e*) Compare the fields of *C* and *D* with those which would belong to similarly shaped bar magnets.

(*f*) How is the strength of the field affected by increasing the strength of the current? By increasing the number of turns in the coil? What effect is due to the permeability of the soft iron core?

(*g*) What name is given to a helix or flat coil having a soft iron core and carrying a current? What special advantages has it?

(*h*) What can you infer as to the behavior of all such coils and helixes toward each other and toward magnets? Try to find applications of electromagnets.

NOTE.—The current strength should be from five to twenty Amperes in order to get satisfactory curves, and is best furnished by a direct current dynamo or storage battery, all the apparatus in the laboratory being joined up in series. In this case the teacher will regulate the current by means of a suitable resistance, and inspect the connections before turning on the current. If the school is not equipped with a dynamo one or two chromic acid cells are to be connected in series with each apparatus.

EXERCISE NUMBER 35

SHORT DISTANCE TELEGRAPHY

REFERENCES

A 432–434	GE 379, 380	J J 290–298
C 316	GP 550, 551	M & T 209–215
C & C 507–510, 512, 513	H 419–421, 424, 427	T 499, 500
	H & W 252	W & H 286

Purpose. — The purpose of this exercise is to set up a short distance telegraph line of two stations, to diagram the arrangement, to trace the current through the circuit, to operate the instruments, and to explain their action.

Apparatus. — (*a*) Call the two stations *A* and *B*. At each station there should be one gravity cell, one key, one sounder, some pieces of wire, and a couple of double connectors.

(*b*) A single wire representing the line wire is supported on insulators and runs from *A* to *B*.

Operations. — (*a*) At one station, *e.g.* *A*, connect the − electrode of the battery cell to a wire leading from a gas pipe or water pipe. Both wire and pipe should have been filed till bright, and the wire tightly wound a half-dozen times round the pipe, or still better, soldered to the pipe, thus securing a good "ground connection."

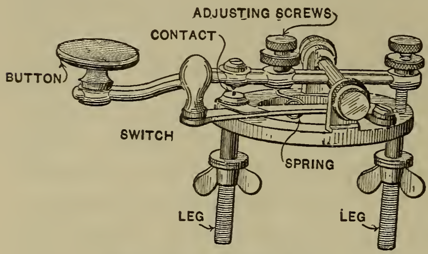

Fig. 26.—Morse Key.

(*b*) At the other station make a similar ground connection with the + electrode of the battery cell.

(*c*) At each station, connect the free electrode of the battery with one terminal of the key. Here and throughout, use double connectors where there are no binding-posts.

(*d*) Draw a neat and legible diagram of the cell and connections as far as now made.

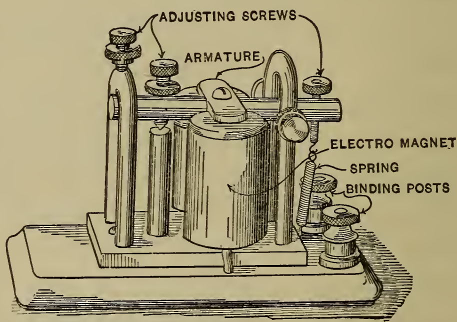

Fig. 27.—Telegraph Sounder.

(*e*) At each station connect the free terminal of the key with one of the binding-posts of the sounder.

(*f*) Join the other binding-post of the sounder to the line wire. The "circuit" is now complete or "closed" and the apparatus is "in series."

(*g*) Before attempting to operate, see that both keys are closed by means of their side levers, or "switches," which are provided in order that the keys may always be closed when no message is being sent. (Why?) Now complete the diagram of the circuit, including all the apparatus at both stations and the line wire, and having due regard to the proportions of the different parts of the apparatus.

(*h*) By means of arrows, trace the path of the current from the zinc of your cell — through the fluid, then through the entire wire circuit, instruments, line, and ground — back to the zinc.

(*i*) Now operate the circuit, sending from each station in turn such Morse signals as may be indicated by the teacher.

(*j*) Make a separate sketch or diagram of the key and of the sounder. By reference to the parts as indicated by appropriate lettering briefly explain the action of each. *Draw from the objects, not the cuts.*

Precautions. — Since oxidized, greasy, or loose connections greatly diminish the current strength (Why?), see that all connections are scraped bright and clean and that the binding screws are firmly set.

Lesson. — This exercise is designed to make the student acquainted with the proper method of setting up the instruments of a telegraph line, and with the manner in which the electric current is used in sending and receiving signals with them.

Exercise Number 36

LONG DISTANCE TELEGRAPHY

References

A 432–434	GE 379–381	M & T 215–217
C 316	GP 550–552	T 499–501
C & C 511–514	H 423–425	W & H 286
	JJ 290–299	

Purpose. — The purpose of this experiment is to study the construction and action of the relay, and to learn why it is necessary on a line of high resistance.

Apparatus. — (*a*) In addition to the apparatus of Exercise 35 a relay and two more cells of battery are needed at each station.

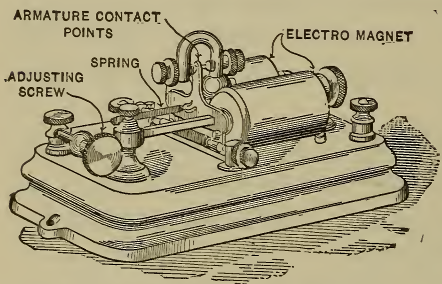

Fig. 28. — Telegraph Relay.

(*b*) The same line wire may be used, but is supposed to be many miles longer, so that the additional resistance makes the current too weak to operate the sounder. If the teacher desire, he may insert a suitable resistance to represent that of the additional line wire.

Operations. — (*a*) Examine the relay, and determine which pair of binding-posts is connected with the ends of the magnet wire. These are called the main line posts.

(*b*) The other two are called the local circuit posts. Trace the metallic paths from them to the air gap between the platinum contact point on the lever and that on the screw against which the lever strikes when the armature is attracted toward the magnet. Notice, when the armature is released and the lever flies back in obedience to the tension of its spring, that the screw against which it now strikes is insulated from it by a tip of hard rubber. Thus there is a break in the metallic path between the two local posts when the armature is not attracted; but this air gap is closed whenever the armature is drawn forward.

(*c*) If a battery cell and a sounder be placed in series with the two local posts, can the relay lever be operated by the hand, so as to act as a key, and thus to work the sounder? Why? Try it, and state what occurs.

(*d*) Now (at each table) disconnect the local wires from their posts, join two cells in series, "ground" the −electrode of this "main line battery" at station *A*, and also ground the +electrode of the main line battery at station *B*. At each station connect the other electrode of the main line battery to one post of the key; connect the other post of the key with one of the main line posts of the relay; and join the free main line post of the relay to the line wire.

(*e*) Diagram the arrangement, and, by means of thin arrows, trace the main line current throughout the circuit.

(*f*) Send a signal from each station to the other in turn. If you fail to receive the signal, first see that the circuit is unbroken excepting at the sending key, and then, if you still fail, ask the instructor to assist you in adjusting the relay.

(*g*) Connect the local battery and sounder in series with the local posts of the relay, as you did in operation (*c*). Can you now operate the relay at *B* by opening and closing the key at *A* (the key at *B* remaining closed)? Does the relay at *A* receive signals sent from *B* in like manner? Do the relays at *A* and *B*, when thus operated, open and close their respective local circuits so that the sounders click in unison with them?

(*h*) Add the local circuits to your diagram, tracing the local battery currents through them. Use thick arrows to indicate that these currents are not the same as that on the main circuit, and are stronger.

Lessons. — (*a*) Does the relay in operation (*f*) act just as the sounder did in Exercise 35? Does it make noise enough to be heard easily, or is the noise faint compared with that made by the sounder in Exercise 35? If the main line resistance be great, can the current work the sounder when connected as in Exercise 35? Why? Is it, nevertheless, strong enough to operate the relay? Does the relay lever act like a key to the local circuit? How does it differ from a key with regard to the immediate source of the energy that moves it? Does the sounder now make noise enough to be heard easily? Is it the main battery current, *or the sound*, which is reënforced by

the use of the local battery and sounder? *State whether or not* any of the local current gets into the main circuit, or any of the main line current into the local circuits.

(*b*) From the *object*, make a careful drawing of the relay, and briefly explain its action. Do not repeat any statements made in answer to questions above.

Exercise Number 37

ELECTRIC BELLS AND DOMESTIC WIRING

References

A 427, 428 C & C 515 H 418
M & T 218 W & H 285

The Purpose of the exercise is to learn how wiring is done for domestic electric bell service.

The Apparatus, Fig. 29, consists of a wooden frame with partitions, which is to represent a sectional model of a house. Electric bells, push buttons, battery cells, and annunciator indicators are mounted on the frame as shown in the diagram. A supply of insulated wires of various lengths are to be used for making the connections, and several binding posts, $B\,p_1$, $B\,p_2$, $B\,p_3$, etc. serve to join the wires where in actual practice they would be permanently joined and covered with insulating tape.

Operations.—(*a*) Remove the covers from a bell and a push button, and make a clear diagram of each. By reference to these diagrams, explain the

action. The diagrams should be lettered, and the paths of the current clearly shown by arrows.

(*b*) Beginning with the carbon of battery cell $B\ a_1$, connect it in series with $B\ a_2$ (*i.e.* carbon with zinc). From the carbon of $B\ a_2$ carry a white leading out wire to one binding post of the bell.

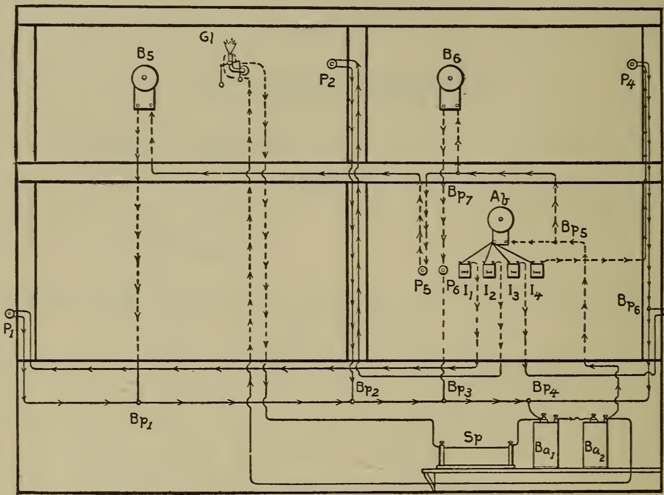

FIG. 29.

(*c*) With white wires, connect the other post of the bell through the indicator I_1 with one side of the Front Door Push Button P_1. Also connect the other side of P_1 by the long, red return wire with the zinc of $B\ a_1$.

(*d*) Diagram the arrangement, tracing out the circuit with arrows; then press the button to see if the current rings the bell and turns the indicator I_1.

(*e*) In like manner, connect, diagram, and trace the circuits for P_2–I_2, P_3–I_3 and P_4–I_4. Test

them. (Use white wires from battery to button, red wires from button back to battery.)

(*f*) Connect, diagram, and test the circuits for the bells B_5 and B_6 with their push buttons P_5 and P_6.

OPTIONAL PROBLEMS

(*a*) Connect the spark coil *Sp* with the battery and the gas lighter *Gl* as indicated. Diagram the circuit. Connect the gas burner with the gas supply by means of a rubber tube, and turn on the gas at the supply pipe. Operate and study out the action of the spark coil and gas lighter. (The reason why the coil gives a spark will be learned in Exercise 38.)

(*b*) Connect the three bells *in series*, i.e. *so that the current goes from the battery through one bell after another, and back through a button to the battery.* Diagram, trace circuit and test.

(*c*) Connect the three bells *in a parallel arrangement or multiple arc*, i.e., *so that the current splits up among them.* After uniting the branch circuits (shunts) at a common point, connect this point through one of the push buttons to the return wire. Diagram, trace currents with arrows, and see if all the bells will ring when the button is pressed.

(*d*) A battery of four cells may be connected all in series, (*i.e.*, carbon of 1 to zinc of 2, carbon of 2 to zinc of 3, etc.) or all parallel (*i.e.* all the carbons to the leading out wire, and all the zincs to the return wire), or in two series of two each, the two series being themselves joined parallel. Try to think out which of these arrangements would be best for the arrangement of the bells in series and which best for the bells in multiple arc. Confirm or overthrow your conclusion by testing the matter out and seeing which arrangement of the cells gives the best effect with each arrangement of the bells [Problems (*b*) and (*c*)].

(*e*) Introduce into the branch with one of the bells [as in Problem (c)] a wire several meters long, thus making the current on that branch encounter much more resistance. Does that bell now ring well? In general, if a number of bells or other magnetic devices are to be worked in parallel by the

same battery, how should the amounts of resistance that the branch currents have to overcome compare with one another? This problem suggests a very common trouble with bells and clocks when wired in multiple arc.

(*f*) Bells at Home.—After Working out this Exercise the student should keep the bells at home in working order. The bell is adjusted by the little contact screw near the clapper. Printed directions for renewing the batteries are pasted on the jars.

Exercise Number 38

INDUCED CURRENTS

References

A 388, 389	GP 515–521	M & T 229–237, 268, 269
C 229–305	H 396–398	T 222–226
C & C 480–484	H & W 259–263	W & H 313–315, 327–329
GE 356, 357	JJ 132–138, 140–142	

Purpose. — It is proposed in this exercise to investigate the laws of induced currents.

Apparatus. — The appliances consist of a coil of many turns of fine wire (secondary), and another of fewer turns of coarser wire (primary), which fits into the former; a soft iron core, a bar magnet, a sensitive galvanometer (D'Arsonval or astatic), and two cells in series.

Operations. — (a) Set up the galvanometer and connect its terminals by means of a shunt; touch the galvanometer terminals to the leading wires from the battery, and make note of the direction of the current which gives a deflection to the right, so that in the experiments the directions of the induced currents

may be observed by noting the directions of the resulting deflection. Remove the shunt.

(*b*) Connect the galvanometer terminals by long wires with the terminals of the secondary coil, keeping the coil and galvanometer as far apart as practicable.

(*c*) Thrust the north-seeking pole of the magnet into the secondary, note the deflection, and trace the direction of the induced current around the coil.

(*d*) From the direction of this current around the coil, determine the direction of its lines of force (Exercise 34), and state whether it caused the end of the coil into which it was thrust to be a north-seeking or south-seeking pole.

Remember that if the current circulates counter-clockwise around the coil as you face its end, the lines of force come out of it; and this end is a north-seeking pole.

(*e*) Was the force of the coil in such a direction as to oppose or to assist the motion of pushing the north-seeking pole up to the coil?

(*f*) Now withdraw the north-seeking magnet pole, and note deflection, direction of current, direction of lines of force, and effect on the motion, as before.

(*g*) Repeat all the observations and notes, using the south-seeking pole of the magnet.

(*h*) Connect the terminals of the primary coil with the battery; determine one of its poles from the direction of the current around it, or by a compass needle (Exercises 33, 34); and then repeat all the experiments and notes made with one pole of the magnet.

(*i*) Reverse the current through primary. Does

its polarity change? Repeat all the experiments and notes as with the other pole of the magnet.

(*j*) Repeat all the experiments with the two coils, having previously placed the soft iron core inside the primary (*b*). State whether the quality or magnitude of the effects has changed, and how.

(*k*) Place the primary inside the secondary, and then (1) close circuit; (2) open circuit; (3) reverse the battery wires and close circuit; (4) open the circuit. Note all the results and compare them, quality and quantity, with those obtained by *inserting and withdrawing* the coil while the circuit *remains constantly closed.*

(*l*) Insert the primary into the secondary and the soft iron core into the primary. Now repeat all the experiments made in (*k*) and compare results.

Inferences. — State the effect produced (*a*) by increasing the number of lines of force passing in a given direction through a closed coil, (*b*) by diminishing the number of lines passing in the given direction through the closed coil (all the movements that were made either increased or diminished them). (Why?)

(*c*) State how the magnitude of the induced E.M.F. is affected by the *rate of change* of the number of lines, which was increased or diminished in the various cases either by changing *more lines* or by *quickening the motion* so as to change the same number in less time.

(*d*) State Lenz's Law, and say whether or not all the observations show that this law is verified in your experiments.

OPTIONAL PROBLEMS

(*a*) Reversibility of the Dynamo and Motor.—Mount two toy motors, A and B, on a board; and belt their two pulleys together with a soft cotton cord, or a weak rubber band. Join the binding posts of A with the two poles of a battery, and those of B with the terminals of a galvanometer. Does B act as a dynamo, and generate a current? Now interchange the battery and galvanometer. Does B act as a motor, and A as a dynamo? Describe the transformations and transferences of energy.

(*b*) Dissect One of the Machines, keeping the parts in a box cover. Diagram the parts. Re-assemble it, and trace the current through all the connections.

With the aid of Figs. 134 and 135, Mann and Twiss' Physics, find out whether it is shunt or series wound. Change it from shunt to series, or vice versa; and operate it as motor and as dynamo.

Exercise Number 39

ELECTRICAL RESISTANCE

References

A 350–353, 414–416
C 312, 324
C & C 460–463, 471, 473, 475, 479
GP 455, 470–473, 479
GE 315, 324–328
JJ 95, 98, 99–101, 106, 107, 151, 152, 154, 160–168
H 377–380, 383–389
H & W 256
M & T 248–256, 258–265, 267–269
W & H 279–280, 290–294

The Purpose is to learn how the electrical resistance of a conductor is measured.

Apparatus.—In one of the most widely used methods of measuring resistance, the Wheatstone Bridge is the principal instrument. It is connected by wires with a battery *B a*, a sensitive galvanom-

eter G, and a wire coil of known resistance r_2. (Cf. Figs. 30 and 31, also Appendix F.)

Theory of the Wheatstone Bridge. — Let there be an arrangement of conductors forming a divided circuit as represented in the diagram.

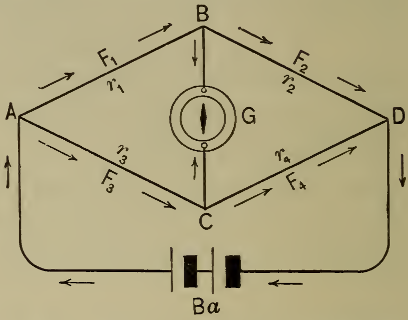

FIG. 30.—Explaining the theory of Wheatstone's Bridge.

Let a current from the battery divide at A into two branches, and reunite at D; and let the point C be so chosen with reference to B that no current passes through a galvanometer, G, in connection with these two points. Then B and C are equipotential points. (Why?) Also, —

let F_1 and r_1 be the fall of potential and the resistance between A and B,

F_2 and r_2 be the fall of potential and the resistance between B and D,

F_3 and r_3 be the fall of potential and the resistance between A and C,

F_4 and r_4 be the fall of potential and the resistance between C and D.

Then $F_1 = F_3$ (being the falls of potential from A to the equipotential points B and C),

and $F_2 = F_4$ (being the falls of potential from the equipotential points B and C to D).

$$\therefore \frac{F_1}{F_2} = \frac{F_3}{F_4}. \quad \text{(Why?)}$$

But $$\frac{F_1}{F_2} = \frac{r_1}{r_2} \text{ and } \frac{F_3}{F_4} = \frac{r_3}{r_4}.$$

(The fall of potential along any part of a conductor is proportional to the resistance of that part.)

$$\therefore \frac{r_1}{r_2} = \frac{r_3}{r_4}. \quad \text{(Why?)}$$

Corollary. — Since the resistances of conductors of uniform material and sectional area are proportional to their lengths, it follows that if *ACD* be a wire of uniform material and thickness, the ratio of the lengths of the segments *AC* and *CD* $\left(i.e. \frac{L_3}{L_4}\right)$, may be substituted for the ratio of their resistances $\left(\frac{r_3}{r_4}\right)$ and we shall have $\frac{r_1}{r_2} = \frac{L_3}{L_4}$. If three of the quantities in either of the above proportions are known (or can be measured), the fourth can be calculated.

Application of the Theory.—The shaded rectangles, Fig. 31, represent thick copper or brass strips whose

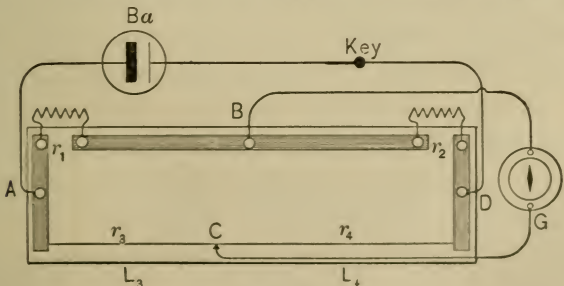

Fig. 31.

resistances are negligible unless extreme accuracy is sought. The straight wire L_3 L_4 is just a meter (sometimes a half meter) long, and as nearly as may be of uniform cross section. It is made of an alloy (German silver or platinoid) which has a relatively high resistance not greatly affected by small changes of temperature. This wire is stretched over a meter rule, and is divided by the sliding contact C into two segments whose resistances will be called r_3 and r_4. Examine Figs. 30 and 31, and note that the distribution of resistances in them is essentially the same, *i.e.* they differ only as to exact shape. Hence the general theory applies to Fig. 31; and (since the wire L_3 L_4 is uniform) the corollary also applies to it.

Measuring Resistance with the Bridge.—(*a*) Close the gap above A with the wire whose resistance is to be determined, making tight connections with the binding posts. Call its resistance r_1 or x. In like manner, connect the known resistance r_2 across the gap above D. If a box of resistance coils is furnished for this purpose, join its binding posts with those of the bridge by means of short, thick wires. (Why?) Connect the battery B a, the galvanometer G, and a telegraph key or a push button, as shown in the diagram. Take care that all the metallic contacts are scraped clean and bright and the binding posts firmly set. (Why?)

(*b*) See that the galvanometer is properly leveled, and that the pointer stands at zero. (Cf. Appendix F.) Close the key, and slide the contact piece C

along the meter rule, until a point is found such that when contact is made there the galvanometer pointer shows no disturbance. *Do not stretch or scrape the wire.* (Why?)

REMARKS.—When beginning the experiment, have the galvanometer shunted, and remove the shunt when the deflections become small. First make contact with C at distances of 10 cm. along the wire, beginning at the left end, until the galvanometer reverses its deflection: then go back toward the left end, making contact at distances of 1 cm. When the galvanometer again reverses, and the point of no deflection is thus located within 1 cm., go toward the right again by steps of 1 mm.

Avoid heating the wire in any way. (Why?)

Leave the key open when the bridge is not in use.

It is best to select such a known resistance that the point of no deflection comes near the middle of the wire. This may be easily done in a rough preliminary experiment. When this plan is adopted the errors due to non uniformity of the wire are much less serious. (Why?)

(*c*) Test the adjustment by seeing if equal and opposite deflections are caused by making contact at equal short distances on the right and left of the point of no deflection. If necessary, readjust until the point that satisfies this condition is found.

(*d*) Read and record in millimeters the lengths L_3 and L_4 of the segments into which C divides the wire.

(*e*) From the corollary to the general theory it is plain that $r_1 = \frac{r_2 L_3}{L_4}$. Substitute the values of the three known quantities and calculate the unknown resistance.

(*f*) Now interchange the known and the un-

known resistances, repeat the operations, solve the equation for the new value of the unknown resistance, and take as the probable true value the mean of the two determinations.

OPTIONAL PROBLEMS

(*a*) AMMETER AND VOLTMETER METHOD. — Connect an ammeter in series with a glow lamp, and also connect a voltmeter as a shunt across the terminals of the lamp. Pass the current through the lamp so as to light it up, take a series of readings of the meters, and find the mean reading of each meter. From Ohm's Law, Ohms resistance = Volts lost in the lamp ÷ Current strength in amperes. Calculate thus the *"hot resistance" of the lamp.* Compare this with its cold resistance obtained with the Wheatstone Bridge. Does the resistance of carbon rise or fall with increase of temperature?

Since Power in Watts = Volts × Amperes, you have the data for calculating in watts the rate at which the lamp uses energy. Calculate it.

(*b*) FIND THE HOT AND THE COLD RESISTANCE of an electric heater, such as is sold for flatirons, chafing dishes, etc., proceeding as suggested in Problem (*a*). State what effect raising the temperature of the metallic wire of the heating coil has on its electrical resistance. Compare with carbon (Problem *a*).

(*c*) RELATION OF RESISTANCE TO LENGTH. — Measure off (say) 6 meters of Number 28 B & S gauge German silver wire, and determine its resistance with the bridge. Determine also the resistance of $\frac{2}{3}$ and of $\frac{1}{3}$ of its length. Express decimally the ratio of each resistance to the corresponding length, and tabulate all the results. Do you find that the ratio of resistance to corresponding length is a constant one? State the law of resistance which may be verified by such experiments. The quotient obtained by dividing the resistance by the length in cm. also represents the resistance of a centimeter of wire of the given material and sectional area. This being known how may the resistance of any number of cm. be calculated?

(*d*) RESISTANCE AND SECTIONAL AREA. — As suggested in Problem (*c*) measure the resistances R and R', of 6m. each of 28 and 16 or 18 German silver wire. With a micrometer

screw caliper (cf. Appendix B Art. 5), determine their diameters; and from the diameters calculate their sectional areas, a and a'. Find the products Ra and $R'a'$; and see how near equal they are. If they are so nearly equal that you may regard the difference as experimental error, you may write $Ra = R'a'$. Prove that if this equation is true then $\frac{R}{R'} = \frac{a'}{a}$. State the law of resistance which this proportion expresses.

(*e*) Resistance and Material. — Measure the resistance of 6m. of 28 copper wire, compare it with that of the German silver wire of the same dimensions. Other things being equal, the resistance of a German silver wire is found to be how many times as great as that of a copper wire? State the law of which this is a particular case.

(*f*) Resistivity. — Having measured the lengths, sectional areas and resistances of any or all the wires mentioned in Problems (*c*), (*d*), and (*e*), find the quantity $\frac{Ra}{l}$ for each (*i.e.* multiply the resistance of 1 cm. by the area of cross section *in square centimeters*). This quantity for a given substance is called its resistivity or specific resistance.

Exercise Number 40

STUDY OF A SIMPLE VOLTAIC CELL

References

A 346–349, 385–385 *d*	H 346–355
C 294–297	H & W 243–246
C & C 428–442	JJ 30–36, 40–44, 47–55
GE 297–304, 308, 309	M & T 207–212, 272–281
GP 429–441, 467	W & H 269–271, 274–277

Purpose. — The purpose of this exercise is to investigate the action of a simple voltaic cell.

Apparatus. — The apparatus and materials consist of a battery jar, nearly full of dilute sulphuric acid (1 part acid to 20 parts water), two zinc plates, one of them amalgamated with mercury, a copper plate,

a wooden cleat with two saw cuts in which to support the plates, a compass, and a double connector.

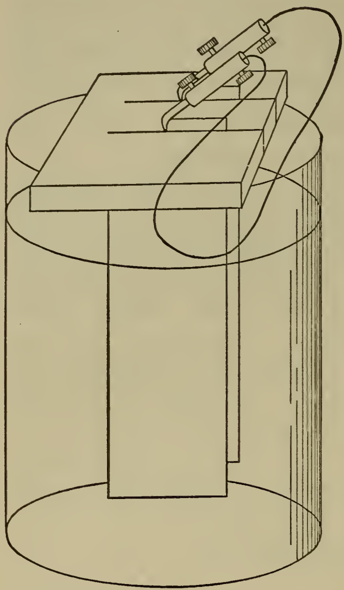

FIG. 32. — Showing method of supporting and connecting the plates.

Preliminary Directions. — (*a*) Caution! Throughout the experiment the jars and plates should be kept in a tray of sheet lead provided for the purpose. The acid is very destructive, and under no circumstances should it be allowed to drip on the table or clothing. Should such an accident occur, quickly wash away the acid with a weak ammonia solution, followed by plenty of water.

(*b*) Do not inhale the unpleasant fumes.

(*c*) Do not allow the amalgamated zinc to touch either of the other plates.

(*d*) In describing the apparatus, make a diagram showing (1) cell with plates and liquid in position, wires joined, and compass needle in the observed attitude; (2) plates, marked respectively Cu (copper) and Zn (zinc); (3) electrodes, marked respectively + electrode and − electrode; (4) solution, marked sulphuric acid; (5) direction of current.

(*e*) After each observation, remove the plates *promptly* (to a jar of water, which should stand ready in the tray).

(*f*) Before beginning each operation, see that the liquid has cleared of bubbles previously formed.

Operations. — (*a*) Place the copper strip in the acid. Is any chemical action indicated by gas bubbles rising from the plate?

(*b*) By means of the cleat, support the copper and the unamalgamated zinc side by side in the acid, not allowing either the plates or their wire terminals to touch each other. Is there now any chemical action? If so, from which plate do the bubbles come? Note, as well as you can, the rapidity of the action, so as to compare it with that in other cases.

(*c*) By means of a double connector, join the wire that leads from the copper (*i.e.* the + electrode) to the wire that leads from the zinc (*i.e.* the − electrode). Do bubbles rise from either or both plates? If from both, from which plate do the most bubbles come off? Is the action more vigorous than in Case (*b*)?

(*d*) Pass the wire in a north-south direction *over* the compass needle. Is the needle deflected? As you look along the wire, does the *north-seeking* pole move in the clockwise or counter-clockwise direction with regard to the wire? Then, remembering the relation of lines of force to current which you learned in the preceding exercise, state whether the current passes along the wire from copper to zinc, or in the reverse direction.

(*e*) Replace the unamalgamated zinc by the amalgamated, leaving the circuit open; and compare the observations with those of Case (*b*). Record the result.

(*f*) Join the electrodes. Where do the bubbles originate now? Compare the vigor of the action with that in Case (*c*). Record the result.

(*g*) Pass the wire over the compass, as in Case (*d*). Is the direction of the current the same? Is the strength of the current greater (indicated by a greater deflection)?

(*h*) Compare the two zincs, and (if possible) note which has wasted the most by the chemical action. (The only certain way is to expose them equally and weigh each before and after.) Does the copper show any signs of wasting?

(*i*) Note whether any heat energy has developed, as indicated by plates or liquids becoming warmer.

Carefully space your notes, writing them in columns headed Operations, Observations, Inferences, so that each operation and its corresponding observations and conclusions shall stand out prominently on the page.

Lessons. — (*a*) *Energy changes.* 1. If the electrodes are tested on open circuit by means of a very sensitive electroscope (or electrometer), the + electrode shows a positive electrostatic charge and the − electrode a negative charge. Chemical potential energy of zinc and acid has been transformed into electrical potential energy.

2. When the circuit is closed, this is transformed into electrokinetic energy, associated with the con-

ducting wire. 3. This energy can do several kinds of work. (What kinds?) The supply of energy is kept up at the expense of zinc and acid as long as the circuit remains closed, or until the chemical potential energy is exhausted.

(*b*) Since the zinc wastes away, and the copper does not, it is evident that the chemical change takes place at the zinc plate and not at the copper. But the hydrogen bubbles originate at the copper plate. Therefore we conclude that the chemical action is handed along from molecule to molecule through the liquid.

(*c*) Amalgamating the zinc largely prevents "local action," due to iron or carbon particles existing as impurities in the commercial zinc. By local action chemical energy is transformed into heat in the cell and is wasted, instead of being wholly transformed into electrokinetic energy, available in the external circuit.

Exercise Number 41

ELECTRO-PLATING

References

A 357, 358, 414, 429–431	H & W 251, 254, 255
C & C 445–451, 464, 472	JJ 57–67, 96, 145, 153, 155–159, 370–383
C 297, 298, 307–309, 324	M & T 272–285
GP 442–445, 451, 452, 463–467, 548, 536	T 162, 178, 190, 212, 236–245, 492–496 *a*
GE 307, 313, 322, 333, 371, 377	W & H 279–280, 290–294, 306–312
H 365–370, 382, 393	

Purpose.—The purpose of this exercise is to learn

how electroplating is done, and observe some of the phenomena of electrolysis.

Apparatus.—If an iron object such as an ordinary key is to be plated with copper, you must have a copper plate like that used in Exercise 40, a battery jar containing the plating solution (some salt of copper dissolved in water), some source of steady current (dynamo, or three Daniell or gravity cells). You will need a cleat, like that of Exercise 40, or some other convenient device for supporting the copper plate and key in the fluid, and some wire hooks, connecting wires, and double connectors. For cleaning the article to be plated use a plater's scratch brush (or any stiff brush with powdered pumice stone), and a jar of cleaning acid must also be at hand.

The Dynamo Current, if used, should be regulated by the teacher with the aid of a variable resistance, and should be distributed to the tables in series *i.e.* the current should pass through the apparatus at each table in succession, not be split up among them.

Cleaning Acid for Iron is made by slowly pouring 15 parts of commercial sulphuric acid into 125 parts of water (with thorough stirring) in a stone jar, and adding 1 part each of nitric and hydrochloric acids.

Copper Plating Solution for Iron.—(*Caution!* The Cyanides, used in this solution are *deadly poisons*. Acetate of iron is the antidote, but if any considerable quantity were swallowed, the patient would probably die. Great care should be taken not to get the solution on the hands, as the poison will act by absorption through a scratch or even through the skin. If the student observes this precaution he is in no danger. It is best, however, to make a rule *never to touch chemicals of any kind with the hands* or *to use them in any way in which they may be spilled on the floor or tables or clothing*.)

Copper cyanide is first prepared as follows: A solution made of 1 part by weight of C. P. (chemically pure) potassium cyanide in 16 parts of pure water, is slowly poured, with stirring, into another solution, made by dissolving 2 parts of crushed copper sulphate crystals in 16 of water. The potassium cyanide solution is added until the green cyanide of copper ceases to be thrown down as a precipitate. The solution is then poured off, and the precipitate washed with water on a filter and dried. To make the plating solution, this copper cyanide is stirred into a solution made of 4 parts C. P. potassium cyanide to 32 parts of water until no more of it will dissolve; and then 1 part of the solution of potassium cyanide is added. The solution works best if kept warm while plating with it.

The cleaning and plating solutions should be made by the teacher, under the fume hood or out doors, as the fumes are injurious. The solutions should be kept in labeled acid bottles when not in use. For the exercise, the cleaning acid is best placed in jars, in the sink, where all may use it.

Cleaning the Object.—If the object is rusty, scour it with sand. If it is greasy rinse it in a hot solution of caustic potash. Rub it thoroughly all over with the scratch brush, using lengthwise strokes, and keeping it wet with water. When it is thoroughly bright at every point, rinse it well with water, and soak it for 5 minutes in the cleaning acid. *Do not lay it down or touch it with the fingers.* If you do, the plating will not stick. Handle it with pincers or a wire twisted around it.

Depositing.—Suspend the cleaned article by a thin copper wire, which is twisted with a firm, clean joint round a heavy copper wire. Place this heavy wire in one slot of the wooden cleat, and the copper plate in the other. With double connectors, join the copper plate (*anode*) with the + (copper) pole of the battery, and the object to be plated (*cathode*)

with the — (zinc) pole of the battery. The anode and cathode may now be lowered into the jar of *electrolyte* (plating solution). They should be about 3 inches apart. Watch for the deposit of copper which begins to form on the cathode. It should be even and firm. If it is dark and powdery, the current is too strong, and should be diminished by increasing the distance between the *electrodes* (anode and cathode), or by otherwise adding to the resistance of the circuit, or by removing a cell. If the deposit is crystalline and forms too slowly, the current is too weak, and another cell should be added or some of the resistance removed from the circuit.

It is better to have two anodes in parallel and place the cathode between them. If there is only one, the object should be turned around occasionally.

With careful attention to these directions, a firm, permanent coating of good thickness should be obtained in about an hour. If the time allowed is too short, or if the deposit does not stick, the cleaning and depositing should be repeated.

If a very thick deposit is wanted, it will be necessary first to give the object a very thin coating in the cyanide solution, remove and wash it, and then to allow it to remain in a plating cell of copper sulphate solution while the current passes for several hours. The *copper sulphate plating solution* is made by dissolving 4 parts by weight of crushed copper sulphate crystals in 20 parts of pure water and slowly stirring in 1 part of sulphuric acid.

This solution should be filtered and kept clean. It is good for copper plating all metals except iron, steel and zinc.

Polishing.—After the object has been plated, it should be washed and polished. This is best done by rubbing it first with a fine scratch brush or the finest emery cloth (always lengthwise), and then with a soft cloth and rouge.

Lessons.—(*a*) State whether in a general way your observations seem to verify the following statement:

"Other things being equal, the amount of metal deposited is proportional to the strength of the current, and also to the time during which it passes."

(*b*) State why the current is weakened by separating the electrodes.

(*c*) Give a reason why such extreme cleanliness is necessary in order to obtain a permanent deposit.

(*d*) What metal should be used as anode, and what metal should be in the electrolyte, in order to plate with silver? With nickel? With gold?

(*e*) Describe any other phenomena which you may have happened to observe in this experiment.

Complete Directions for successfully plating all kinds of articles, and for electrotyping medals, wood cuts, etc. will be found in "Electroplating" by J. W. Urquhart (Van Nostrand, N. Y. 1905).

OPTIONAL PROBLEMS

(*a*) Storage Battery.—Cut from sheet lead two electrodes of the same shape as the plates of the simple voltaic cell (Fig. 32); scrape them clean and bright. Mount them in the wooden cleat, and with the double connectors join one lead

plate through a galvanometer to the + pole of a battery of 3 or 4 gravity or Daniell cells in series, and mark this electrode +. Join the other lead plate to the pole of the battery, and mark it −. Lower the plates into an electrolyte composed of 1 part by volume of pure sulphuric acid to 10 of water, pass the current through the lead cell during 15 minutes to an hour. Note the direction of the galvanometer deflection. Now disconnect the wire from the − pole of the battery and touch it to that terminal of the galvanometer which was next the + pole of the voltaic battery. Do you observe a deflection in the opposite direction? If so state what is happening with regard to the lead cell. Why call it a storage battery? What kind of energy went into it while charging? What kind of work was done in it? What kind of energy came out of it while discharging? See if it supplies energy fast enough to ring a bell or operate a buzzer or a telegraph instrument.

The power of such a cell may be very greatly increased by "*forming*" its plates. This is done by repeatedly charging, discharging through a resistance, allowing it to rest for some time, and then charging in the opposite direction. After forming, it is finally charged for about 30 hours in one direction only. After this it should never be entirely discharged and should never be charged in the other direction. A quicker method of treating the plates is that of "*pasting*" them. To do this make a thick paste of minium or litharge (oxide of lead) and dilute sulphuric acid. Then roughen the plates, by denting them all over with a nail or other sharp instrument so as to make a multitude of little pockets for holding the paste. Spread the paste on firmly with a putty knife, and then set up the cell and charge for 30 hours. A cell to be practically useful should have six plates, 3 + and 3 −, placed alternately, and connected parallel by bolts or clamps. They must be close together and are to be kept from touching by strips of window glass or glass tubing.

Minium is recommended for the + plates and litharge for the − plates.

For full directions for making and operating a practical storage battery, cf. *School Science and Mathematics*, Vol. V, p. 268, April, 1905.

(*b*) Measuring Current Strength.—Place cleaned and

weighed electrodes of copper in filtered copper sulphate solution, and pass the current through it for as long a time as you have to spare, *i.e.* not less than 30 minutes. Record the time of starting and stopping. Wash the electrodes first in water, then in alcohol, dry them over a radiator, and reweigh them. By subtraction, determine the amount of metal lost by the anode, and the amount gained by the cathode. Theoretically these amounts should be equal, but practically they are seldom found to be so. Divide the gain of the cathode in gm. by the time in sec. The result is the amount deposited by this current in 1 sec. Since a current of 1 ampere deposits 0.000328 gm. of copper in 1 sec., the number of amperes in the given current will be found by dividing the amount which it deposits in 1 sec. by 0.000328. If an ammeter or galvanometer was connected in series with the battery and electrolytic cell during the passage of the measured current, and if readings were taken at intervals, the mean of all the readings will represent (on the scale of that particular instrument) the number of amperes that were passing. By making other similar tests with different steady currents the scale of the galvanometer may be calibrated or standardised, and marked so as to indicate current strength directly in amperes. If the instrument used is a galvanometer, it should be connected with a commutator (cf. Appendix F) so that the current may be reversed after each reading. This is to eliminate the effect of any inequalities in the readings on the two sides of the zero.

CHAPTER V

SOUND

Exercise Number 42

SPEED OF SOUND

References

A 184	GE 180	J 18, 24, 25, 31
C 191, 192	GP 157	M & T 311, 312
C & C 180, 181	H 189–191	W & H 339
	H & W 338	

Purpose. — The purpose of the experiment is to determine the speed of sound in open air.

Apparatus. — The appliances required are: (*a*) a surveyor's tape, or a bicycle with an accurate cyclometer attached; (*b*) a stop-watch; (*c*) a pistol and some blank cartridges; (*d*) two thermometers.

Place. — This must be such as to furnish a straightaway stretch of open ground, level, and uninterrupted by trees or buildings. A country road or railroad is best. Such a place can usually be reached by a car line or bicycles, even by classes in a large city.

Operations. — (*a*) Measure off as long a distance as is available, — call the two stations *A* and *B*. They must be half a mile or more apart. If there are several bicycles with cyclometers, let all measure

the distance, average the results, and reduce to feet by multiplying by 5280. If the school own a surveyor's tape, let the distance be measured by that also, and the result averaged with that obtained by the cyclometers.

(*b*) Let half the party go to station B, and the rest remain at A. Let a person at A set the stop-watch, and be ready to start it when he sees the puff of smoke from the pistol. When he is ready he shows a white handkerchief to the person who is to fire the pistol at B.

(*c*) Just before firing, B shows a handkerchief to A.

(*d*) The watch is started at the instant of seeing the puff of smoke, and stopped at the instant of hearing the sound.

(*e*) Let different pairs of students repeat the operations, the teacher standing near the observer and judging each time whether the result of the trial is worthy to be recorded.

(*f*) Now let the two parties exchange the pistol and watch; and let them make a new set of observations equal in number to the first set. The temperature should be taken several times at each station, the thermometer being screened from sun and wind.

Data. — Record in tabular form, the values of the distance, l, and of the time interval, t, observed by the first party, and of the time interval, t', observed by the second party, and of the temperature, T. Also record the average values of l, t, t', and T. Add t and t' and divide by 2 to get the mean time interval.

Calculation. — Since $\text{speed} = \dfrac{\text{distance}}{\text{time}}$, divide the mean value of l in feet by the mean time interval in seconds.

Sources of Error. — Since the time interval is very small, and since the percentage error of the result cannot be less than that involved in measuring the time, the errors in the measurement of l will, therefore, be relatively unimportant.

The personal equation of the observers will be the most serious kind of error, and will be apparent in the variation of the individual values of t and t' from their averages. Unless the day is perfectly calm, the wind will increase the speed of the sound if travelling with it, and diminish the speed of the sound if travelling against it.

This effect will be at least partially eliminated by observing at A and at B alternately. On account of the shortness of the time, the instrumental errors of the watch may also be serious. If the watch can be rated by reference to an accurate clock, the necessary corrections may be applied.

Temperature Correction. — Reduce the observed value of the speed of sound to what it would be at 0° C. by subtracting two feet per second for each degree that the observed temperature is above zero ($S_0 = S_t - 2\,t$).

Lesson. — This exercise illustrates the early methods of determining the speed of sound. In later methods the time of starting and arriving have been automatically recorded by means of the electric

current upon a sheet of paper moved by clockwork (chronograph.) Thus the personal equation is nearly eliminated.

Exercise Number 43

VIBRATION FREQUENCY OF A TUNING-FORK

References

A 192–198, 201	GP 173–176	M & T 318, 321, 322, 332
C 199, 212, 213	H 186, 206–212	W & H 344
C & C 204–208, 226	H & W 335, 344	
GE 174, 192–194	J 7, 9, 39	

Purpose.—The purpose of this exercise is to rate a tuning-fork, or, in other words, to determine the number of vibrations which it makes in one second.

Apparatus.—A pendulum and a fork are mounted on supports fixed to a long board, so that, when they are vibrated simultaneously, the styluses that are attached to them will trace lines very near together

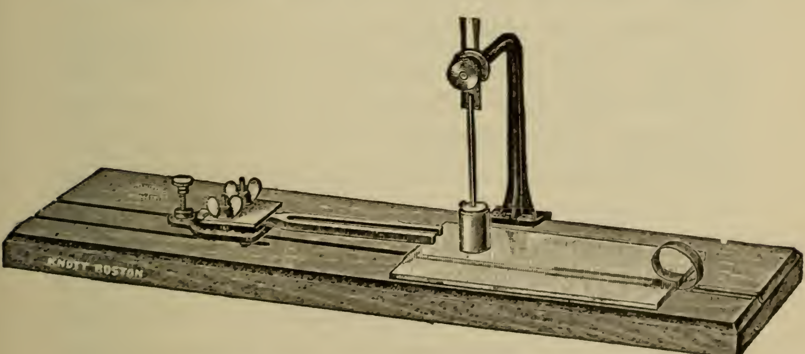

Fig. 33.—Apparatus for rating a tuning-fork.

along a strip of smoked glass. When the glass is drawn swiftly along the board each stylus traces a wavy line, and the line traced by the pendulum crosses and recrosses the line traced by the fork. The height of the fork above the glass, and also that of the pendulum, is adjustable by means of a clamp or screw so that the point of each stylus can press very lightly against the glass. A piano-hammer or a little mallet of soft wood is used to set the fork and pendulum to vibrating.

Operations. — (*a*) Rate the pendulum as described in Exercise 1, page 1. Record three ratings, and take their average as the number of vibrations made in one second by the pendulum.

(*b*) On a block of wood ignite a lump of camphor about the size of a pea, and, holding the glass horizontally about a half-inch above the burning camphor, move it slowly backward and forward until its under surface is entirely covered with a *thin* layer of soot.

(*c*) Now lay the glass on the board, blackened side up. The styluses should be lifted when doing this, so that they will not be bent out of their positions. The styluses should now press very lightly against the smoked glass near its end. See that the glass rests in such a position that it may be quickly pulled along the board in the direction of its length, so as to allow the fork and pendulum to trace their vibrations on it while it is moving. The speed with which the plate ought to be moved must be learned by practice, and is twice as great for a fork

making 256 vibrations as for one making 128 vibrations. (Why?)

(*d*) Set the fork and pendulum to vibrating, and slide the plate.

If the trial is successful, a set of tracings like Fig. 34 will be obtained. It is well to get at least two good traces on the plate.

Each of the spaces, *ac*, *bd*, *ce*, *df*, etc., represents the time occupied by one vibration of the pendulum. (Why?) Also each space from crest to crest or from

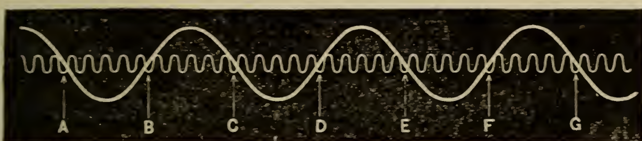

FIG. 34. — Showing the appearance of the smoked glass after taking the tracings.

trough to trough of the wavy line traced by the fork represents one complete vibration of the fork. Count the number of vibrations and tenths of a vibration of the fork traced between *a* and *c*, *c* and *e*, *e* and *g*, and so on. Make and record at least three different counts. The average of these counts is the number of vibrations made by the fork while the pendulum makes one vibration.

Data. — Tabulate the numerical data.

Let n be the number of complete vibrations which the fork makes while the pendulum is making one complete vibration; let N_p be the number of complete vibrations made by the pendulum in one second, and

let N_f be the number of complete vibrations made by the fork in one second.

Then $N_f = N_p \times n$. (Why?)

A much more accurate method of treating the observations is to count the whole number of vibrations and the fraction of a vibration that were made by the fork *while the pendulum made three or more* vibrations. Divide the former number by the latter to get the n of the above formula. In making the count it is well to mark on the glass every tenth vibration of the fork. The difficulty in applying the method suggested above lies in the fact that it is hard to get a good trace of the required length with the apparatus usually supplied.

Sources of Error. — (*a*) Since the two styluses are necessarily a little distance apart, errors will arise from changes in the speed of the plate during its motion.

(*b*) Errors are involved in estimating the fractions of a vibration.

(*c*) What errors are involved in rating the pendulum?

Lessons. — (*a*) From a table of the notes of the standard scale and their corresponding vibration numbers, choose that note to which the vibration number of the fork that you rated most nearly agrees; and call this the note given by the fork.

(*b*) See if the fork is in tune with the corresponding fork of a standard set by sounding them together and listening for "beats."

(*c*) Compare the notes given by this fork and another of *different frequency* which has been rated by another student, and state what effect the vibration frequency of a sounding body has on the note given out by it.

Exercise Number 44

WAVE LENGTH OF A TONE

References

A 205	GE 187–189	J 56, 58, 61, 62
C 173, 174	GP 168–170	M & T 292–296, 299,
C & C 191–194	H 198–202	301, 314, 323, 324

Purpose. — It is proposed to determine the wave length of the tone given out by a tuning-fork.

The method consists in measuring the length of the air column that will give resonance to the fork and in deducing therefrom the length of the waves.

Apparatus. — (*a*) The tuning-fork should be one making not less than 256 vibrations, and preferably the one whose vibration number has been determined in the preceding exercise.

(*b*) A glass tube not less than eighteen inches long, and having an inside diameter of not less than an inch, is mounted on a suitable support and provided with a convenient means of varying the length of the column of air contained in it.

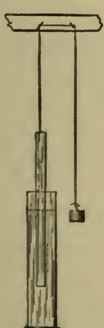

Fig. 35.

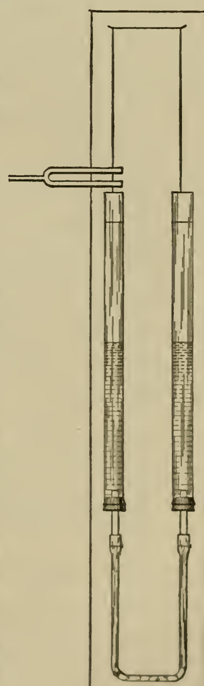

Fig. 36.

Two very convenient forms of apparatus are shown in Figs. 35 and 36. Water is used as a piston, its level in the tube being easily and accurately adjusted in the manner suggested by the illustrations.

Operations. — (*a*) Set the fork in vibration by striking it with a piano-hammer, or a little mallet made of soft wood, and place it close to the mouth of the tube in such a position that one of the prongs executes its vibrations in the line of the axis of the tube.

(*b*) Make the air column evidently too short, and increase its length until a strong resonance occurs.

(*c*) By repeated trials test the adjustment, and try to fix it between definite limits.

(*d*) When satisfied that the length of air column corresponding to maximum resonance has been fixed within the smallest limit, record the amount of this limit, and, with a rule, measure and record the length of the air column, *i.e.* the distance from the water to the end of the tube. Repeat the operations as many times as the time will permit, and record all the observations in tabular form.

Calculations. — Take the average of the numbers representing the length of the resonant air column. Theoretically, this is $\frac{1}{4}$ the length of the wave, but experiments have shown that the diameter of the tube affects the length of the resonant column. A correction equal to $\frac{1}{4}$ the internal diameter of the tube should be added to the mean length of the latter as determined above.

The wave length of the tone given out by the fork is then obtained by multiplying the corrected length by 4. (Why?)

Resonance occurs when the air column is $\frac{3}{4}$ or $\frac{5}{4}$ the wave length, but these cases are not here considered.

Sources of Error. — The most important error is that involved in the judgment of the observer as to when the loudest resonance occurs. State the distance through which the piston had to be moved each way from the position for maximum resonance before the sound became unmistakably fainter. What per cent is it of the length of the column? The percentage error of the result cannot be less than this unless the mean of a long series of observations is taken.

Lessons. — (*a*) This exercise is intended to familiarize the student with the theory of resonance, and afford practice in a simple method of directly determining wave length.

(*b*) Since a wave traverses a distance equal to its own length during one complete vibration, it is clear that the velocity of sound or the distance traversed in one second = wave length × vibration frequency. Calculate the velocity of sound from the wave length and the vibration frequency of the fork. Compare it with the velocity obtained in Exercise 42. In order to compare them, the units of length must, of course, be the same, and both values must be reduced to what they would be at 0° C., as in Exercise 42.

Knowledge of wave lengths and of the various methods of measuring them is of little *direct* practical value, but has proved to be immensely important in developing the theory of air waves and ether waves. In consequence of this theoretical knowledge musical instruments have reached increased perfection; and the discovery of wireless telegraphy became possible.

Exercise Number 45

CAUSE OF OVERTONES

References

A 199, 200
C 200, 209
C & C 210, 211, 213–215, 220–222
GE 195, 197
GP 179–182, 185, 186
H 221, 223–225
H & W 336
J 54–55
M & T 299–301, 317, 327–332, 337–345

Purpose. — The purpose of this exercise is to determine the positions of the nodes and segments of a musical string when vibrating under certain conditions, and to investigate the relations of these nodes and internodes to the overtones given out by the string.

Apparatus. — A sonometer, which consists of two piano wires stretched over a pair of frets at the ends of a suitable sounding-board. The wires pass over a fixed bridge near one end and differing tensions may be applied to them by means of weights or spring balances. A movable bridge is also provided. If the tensions are applied by means of weights, pulleys or levers shaped like the quadrant of a circle, are used to change the direction of the forces from horizontal to vertical.

A violin bow, a cake of rosin, and a number of bent paper strips, to be used as riders, are also required.

If no sonometers are available, the wires may be stretched over the laboratory table; and wooden

wedges placed thereon take the place of the bridges. If spring balances are used, they may be so arranged that the tensions can be accurately adjusted by means of a pair of long screws which pull in the lines of the wires.

Part A

Operations and Observations. — (*a*) See that the sonometer is securely fastened to the table by means of a clamp or handscrew, and that the tensions draw the wires in horizontal lines parallel with the length of the sounding-board. The wires should rest but lightly on the frets that are next the stretching forces.

(*b*) Insert a movable bridge so that the length of one of the wires between the two bridges shall be (say) one meter. Now bow the wire *near* (*not at*) the middle. Can you see the part between the bridges vibrating as a whole? Apply such a tension as will cause the wire to give a full round note. Drop paper riders so that they will bestride the wire at several points along its length. What happens to the riders? What does this indicate about the condition of the wire at the places where the riders were placed?

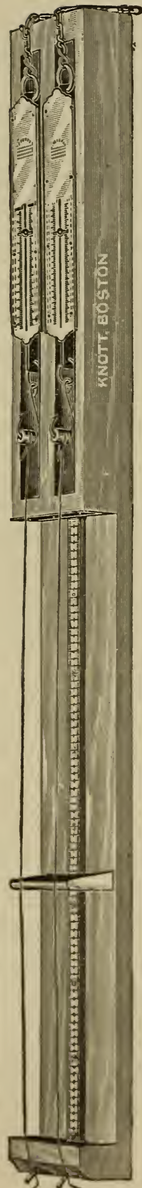

Fig. 37. — Sonometer in which the tensions are measured by spring balances.

By repeated trials ascertain whether there is any part of the wire that is not in vibration when it has been bowed or plucked near its middle point.

(*c*) Carefully listen to the tone and try to keep it in mind. It is called the fundamental tone of this string, with the given length and tension. State whether the string vibrates as a whole when it gives its fundamental tone. Where are the nodes, or stationary points? Illustrate the condition of the string and the behavior of the riders by a diagram. Write "Fundamental" beneath the diagram.

(*d*) Place riders at the ends and at the three points which divide the string into fourths. Call the riders and the points at which they are placed 0, $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, and 1. Now press, not too heavily, with the finger upon $\frac{1}{2}$ and apply the bow near 0. Immediately after the bow is removed, remove the finger also. Which riders remain quiet and which are agitated? Repeat until sure that certain riders remain quiet while certain others are violently disturbed. State the conditions of the points of the string where the riders had been placed. Illustrate by a diagram as in (*c*). Mark the nodes on the diagram. The vibrating parts between the nodes are called internodes or segments. Mark them also on the diagram.

(*e*) Repeat the operation once more and listen to the note given out by it. Compare it carefully with the fundamental by sounding first one and then the other. (To sound the fundamental, you have only to remove the finger from the point $\frac{1}{2}$.) Is it the

octave of the fundamental? If so, make another diagram and write "Octave" beneath it.

(*f*) Place riders at points 0, $\frac{1}{6}$, $\frac{1}{3}$, $\frac{1}{2}$, $\frac{2}{3}$, $\frac{5}{6}$, and 1. Repeat the former operations, but damping with the finger at $\frac{1}{3}$ and applying the bow at point near 0. Make sure of the positions of the nodes and segments before trying the next case. Illustrate by diagram as before, marking nodes and segments.

(*g*) Listen to the tone given out by the string when vibrating as it does in this case and compare it with the fundamental and the octave. Is it the fifth (or sol) above the octave? If so, write "Fifth above the Octave" under the diagram.

(*h*) Place riders at points dividing the string into eighths and make experiments similar to the preceding. Damp at $\frac{1}{4}$ and bow near 0.

Illustrate by diagram as before, marking nodes and segments.

(*i*) Compare the resulting tone with the fundamental and first octave. Is it the second octave? If so, write "Second Octave" beneath the diagram.

Part B

(*a*) Bow the string (without damping) near the point 0, and listen carefully to the note. Can you detect the octave, the fifth above the octave, or the second octave sounding along with the fundamental? If you are *sure* that you can detect any of these, record the fact.

(*b*) Bow near 0 and *afterward* damp the wire by touching it very lightly with a feather or a bit of blot-

ting-paper at $\frac{1}{2}$. Does the fundamental cease? Do you hear the octave? If so, record the fact. Can you infer from this that the octave and the fundamental were sounding at the same time before the wire was damped at $\frac{1}{2}$? Was the wire vibrating as a whole and in halves at the same time? Why did the octave come out more clearly after damping?

(*c*) Bow near 0 and damp with the feather at $\frac{1}{3}$. Does the fundamental cease? Do you hear the fifth above the octave? Can you make inferences similar to those of (*b*)? State them.

(*d*) Bow near 0 and damp at $\frac{1}{4}$. Make a set of observations and inferences similar to those made in (*b*) and (*c*), but applying to the *second octave* and *four vibrating parts*.

Data. — Copy the tabular form and fill the blanks.

Point where bowed	$\frac{1}{2}$	0	?	?
Point where damped	—	$\frac{1}{2}$	?	?
Number of nodes	2	3	?	?
Number of segments	1	?	?	?
Resulting tone	Fundamental	Octave	?	?

Inferences. — (*a*) State whether from your experiments you are justified in inferring that a string or wire can vibrate as a whole and in parts at the same time.

(*b*) State the number of vibrating parts or segments which correspond to fundamental, the octave, the fifth above the octave, and the second octave, respectively.

(*c*) Define an overtone.

(*d*) When the tones mentioned in (*b*) are present as overtones, what is the *cause* of their presence along with the fundamental?

(*e*) State whether or not you can discern any difference in the *quality* of the tone, first when the overtones accompany the fundamental, and then when they do not accompany it.

Exercise Number 46

LAWS OF VIBRATING STRINGS — LENGTH

References

A 209, 210	C & C 210–212	H 220–222	M & T 298–301,
C 215	GE 196	H & W 339	317–320, 335,
	GP 179	J 50–53	336

Purpose. — The purpose of the experiment is to verify the law for the relation of the length of a stretched string to its vibration number.

Apparatus. — This is the same as that used in the preceding exercise. A second movable bridge is necessary.

Operations. — (*a*) Adjust the movable bridge so that the vibrating part of one wire, *A*, is (say) one meter long, and increase the tension until the wire, when bowed or plucked near the fixed bridge, gives

a good clear note. Call this note do_1, and adjust the tension and length of the other wire, B, so that it gives the same note. It is to be used for reference. Students who have studied music will tune the two strings to unison without difficulty. Those who have not trained musical ears can tune the second string until they begin to hear *beats*, and then cautiously shift the bridge or change the tension until the beats can no longer be heard. While the two strings are sounding together, as unison is approached, the beats diminish in number.

(*b*) Move the bridge under A to such a point as to make the length of the vibrating part exactly $\frac{4}{5}$ what it was at first, and sound A and B successively.

If necessary, hold the wire against the movable bridge by pressing lightly against it with the finger at a point just outside the bridge.

Repeat several times. Do you recognize the interval known in music as do_1-mi_1 (major third)? If so, record it. If the two strings do not seem to give this interval accurately, restore the bridge to its original position, and test the two strings to see if they are in tune, then repeat the operation.

(*c*) By means of the movable bridge reduce the length of the vibrating part of A to $\frac{2}{3}$ of its original length, and repeat the previous operations. Is the interval do_1-sol_1 (major fifth)? Test as before.

Leaving A of the length to sound sol_1, carefully tune B to unison with it (by means of its movable bridge). Now make the length of the vibrating part of A exactly $\frac{1}{2}$ what it was at first, and observe the

musical interval as before. Is it sol_1-do_2? If necessary, make sure by testing the two wires for unison when sounding sol_1, and repeating the observation.

(*d*) If time permits, tune *B* to unison with *A* at do_2, and then reduce the length of *A* to $\frac{1}{3}$. Observe and test the interval as in the previous operations to learn if the interval is do_2-sol_2.

Data. — Tabulate results as follows, appropriately filling the blanks: —

LENGTH	100 cm.	80	66.66	50	33.33
Length ratio: $\frac{\text{New length}}{\text{Original length}}$	1	$\frac{4}{5}$	$\frac{2}{3}$	$\frac{1}{2}$	$\frac{1}{3}$
New note	do_1	?	?	?	?
Interval	Unison	?	?	?	Octave + fifth
Vibration ratio of interval: new note to fundamental	1	$\frac{5}{4}$	?	?	?

Sources of Error. — Errors may arise from unobserved changes of adjustment, but the most serious error, of course, lies in the judgment of the hearer as to the accuracy of the interval. This experiment may be performed with much greater accuracy and completeness by using one string and a set of standard forks of known vibration numbers, and tuning the string to unison with each fork in turn by chang-

ing the length only. The lengths and vibration numbers can then be directly compared. This method, however, is not adapted to the equipment of most elementary laboratories.

Inferences. — Compare the ratio between each new length and the first length with the ratio between the vibration number of the corresponding new note and the fundamental. What must be done with each ratio of the vibration numbers in order to make it equal to the ratio of the corresponding lengths? State the relation of the frequencies of the notes to the corresponding lengths of the string. This is sometimes called the First Law of Vibrating Strings.

Exercise Number 47

LAWS OF VIBRATING STRINGS — TENSION

References. — These are the same as those for Exercise 46.

Purpose. — The law that states the relation of tension of a string to the vibration number is to be verified.

Apparatus. — The apparatus used in Exercises 45 and 46 is to be used in this experiment.

Operations. — (*a*) The two wires are put under tensions of about two or three pounds each. The tensions should be made as nearly as possible exactly equal. The movable bridge is then adjusted under both wires at such a distance from the fixed bridge that the vibrating parts of the two wires are of equal length. If the tensions and lengths are exactly equal,

and the diameters and materials of the two wires the same (as they should be), the two wires when sounded together will be in unison.

If beats are noticed, go carefully over the adjustments of length and tension until these adjustments are correct and the two wires are in tune.

(b) Increase the tension of the wire A until it is four times as great as before. If using the spring balances, do not forget to allow for the *zero correction* as in Exercises 10 and 11. Is the resulting note the octave of the first? Sound B and A successively and compare the notes. By means of a movable bridge make B half its original length, so that it will give the octave of the first note. Are the two strings again in unison? If not, go over the adjustments of tension of A and length of B, see that they are correct, and try again. If the two strings are not in exact unison, is the difference too large to be ascribed to such errors as are likely to exist in the adjustments of tension?

(c) Restore the two wires to their first condition and repeat all the operations, using a tension on A which is nine times as great as the first. Is the note sounded the fifth above the octave? Make B one-third its original length, and test carefully as before to see if the two strings are in unison.

Data. — Call the fundamental do_1, the octave do_2, and the fifth above the octave sol_2. Tabulate the data. If the number of vibrations per second when do_1 is sounded is n, then that corresponding to do_2 is $2n$. What is that corresponding to sol_2?

Inference. — (*a*) Compare the tensions and the corresponding vibration numbers. What has to be done with the former in order to make the latter proportional to them?

(*b*) State the law that is verified by the observations made in this exercise.

Exercise Number 48

LAWS OF VIBRATING STRINGS — DIAMETER

References. — These are the same as those for the two preceding exercises.

Purpose. — The law of the relation of vibration number to diameter is to be verified.

Apparatus. — This is the same as in the three preceding exercises, except that the two wires used should have diameters which bear a simple relation to each other. If Nos. 22 and 28 B. & S. gauge are used (or 18 and 24), the diameters will be very nearly as two to one. A vernier caliper or micrometer caliper is needed for determining these diameters.

Operations. — (*a*) By means of the movable bridge and a suitable tension, adjust the larger wire, A, so that it gives a clear note. Make the length and tension of the smaller wire, B, exactly the same, and carefully compare the two notes. Is the note given by B the octave of that given by A? If not, go over the adjustments carefully.

(*b*) Make A one-half the original length, and see if the two notes are in unison. Test the adjustment as in the previous experiments.

(*c*) Measure the diameters of the two wires.

Data. — Tabulate under the following heads: —

Diameter	A	B
Note	do_1	?
Frequency	n	?
Ratio $\frac{\text{Frequency } A}{\text{Frequency } B} = ?$		
Ratio $\frac{\text{Diameter } A}{\text{Diameter } B} = ?$		

Sources of Error. — Briefly state the principal sources of error.

Inferences. — (*a*) What must be done with the ratio of the frequencies in order to make a proportion with the ratio of the diameters?

(*b*) Can the lack of exact proportionality be fairly ascribed to experimental errors?

(*c*) State the law verified in the observations.

(*d*) Other things being equal, what is the relation of diameter to mass per unit length?

$\Big($Mass$_A$ = volume$_A$ $\times$ density $= \frac{1}{4}\pi \times (\text{diameter}_A)^2 \times 1 \times$ density, and mass$_B$ = volume$_B$ $\times$ density $= \frac{1}{4}\pi \times (\text{diameter}_B)^2 \times 1 \times$ density. $\therefore \frac{\text{mass}_A}{\text{mass}_B} = \frac{?}{?}.\Big)$

What, then, is the relation of the *vibration numbers* of two strings to their *masses per unit length?*

Try to find and understand applications of the laws of vibrating strings in various musical instruments.

CHAPTER VI

LIGHT

Exercise Number 49

BUNSEN'S PHOTOMETER. LAW OF INVERSE SQUARES

References

A 267, 268	GP 286–288	J 7–10
C & C 238	H 447–449	M & T 376
GE 223–225	H & W 276	W & H 366, 367

Purpose. — The purpose of this experiment is to verify the law of inverse squares for light by the method of Bunsen's photometer.

Apparatus. — The photometer consists of a meter rule and three square blocks, each of the same thickness as that of the rule. The blocks can slide along

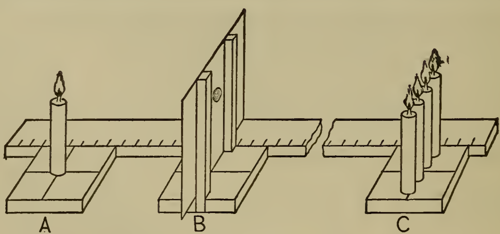

Fig. 38. — Simple form of Bunsen's Photometer.

the table beside the rule, whose face is just flush with their upper surfaces. Each block has a pair of diameters accurately scratched upon its upper surface

by means of a knife and square. One of the blocks, *B*, carries a pair of uprights, to which a screen of white paper may be attached by bits of soft wax, the centre of the screen being over the centre of the block. At the centre of this screen is a circular grease-spot (made by driving into it, with a hot flatiron, a bit of paraffin). One block, *A*, carries a single candle at its centre, and the third, *C*, a row of four candles set close together, two on each side of the centre of the block. The centres of the candles are on the diameter of the block, that is, perpendicular to the length of the rule. Shallow holes are bored into the blocks to receive the candles. The apparatus should be used in a thoroughly darkened room, and screened from the light of the other tables, or, better still, enclosed in a long box with chimneys at the ends, and with doors or opaque cloth curtains on the side toward the observer. With this latter arrangement the room need not be absolutely dark.

Operations. — (*a*) See that the five candles are all of the same height, and that their wicks are trimmed and bent down slightly, so that they give flames as nearly as possible of the same size. Trim them if necessary.

(*b*) Place the blocks *A* and *C* against the rule near its opposite ends.

(*c*) Slide the block *B* along the rule until the grease-spot ceases to be visible when seen from a point a little to the right of the edge of the screen, and read on the rule the position of the knife scratch upon which the screen rests.

(*d*) Now make a second setting in precisely the same manner, observing the spot from a position as far to the left of the edge of the screen as the first point of observation was to the right of it. Read on the rule the position of the knife scratch corresponding to the disappearance of the spot. Record the average of these two settings as the mean position of the screen.

(*e*) Read the positions of the knife scratches on the blocks A and C, and record them as the positions of the two lights. By subtraction determine the distances of the two lights from the screen.

(*f*) Change the position of one of the lights, and repeat the settings. Make as many pairs of readings as the time permits.

Data. — Record the results of each setting in a column, each result opposite its proper heading.

NUMERICAL DATA

Trials		
Readings, scratch A		
Readings, scratch C		
Readings, scratch B right		
Readings, scratch B left		
Readings, scratch B mean		

NUMERICAL DATA — *Continued*

Distance AB		
Distance CB		
Ratio $\frac{CB}{AB}$		
Light emitted by A	1	
Light emitted by C	4	

Sources of Error. — State the errors which may be due to (*a*) the candles; (*b*) the position of the observer, and his judgment; (*c*) light received by the screen from sources other than the direct rays of the candles. If *all* extraneous light be not excluded, the results will be thoroughly unreliable.

Inferences. — We assume that when the spot disappears at the mean position of the screen, the two surfaces are illuminated with equal intensities.

(*a*) If four candles, at distance CB, give *the same illumination to the screen* as one candle does at distance AB, what is the intensity of illumination by *one* candle at CB as compared with that by one candle at AB?

(*b*) What must be done with the ratio of the distances $\frac{CB}{AB}$ in order to make it equal to the ratio of the intensities with which *one candle illuminates the screen* at these two distances respectively. (Both ratios should be reduced by performing the indicated

division.) If there is a decimal remainder to $\frac{CB}{AB}$, can it fairly be ascribed to experimental error? State the law that is verified in this case.

Additional Work. — If the time assigned admits of further work, the four candles may be replaced in turn by three, two, and one, and the settings repeated. In this case, although it will not be so obvious, the ratio of the squares of the distances will be equal to the ratio of the number of candles used, as before.

Exercise Number 50

Alternative Method

RUMFORD'S PHOTOMETER. LAW OF INVERSE SQUARES

References

A 267, 268	GP 286–288	J 7–9
C & C 235–237	H 441–449	M & T 376
GE 223–225	H & W 276	W & H 366

Purpose. — In this exercise, the principle of Rumford's photometer is to be used to verify the law of inverse squares.

Apparatus. — A white cardboard screen is tacked to a block so as to make the card stand upright. Two square blocks, A and B, have their diameters marked or scratched on their upper surfaces, and are to be used as carriers for five equal pieces of candle. With chalk or pencil a perpendicular is drawn to the screen at its middle point. On this perpendicular,

at about 5 cm. from the screen, is mounted a small cylindrical rod. (A penholder or a lead pencil stuck into a flat cork will do.) Through the axis of the rod are drawn two straight lines, *pq* and *rs*, making

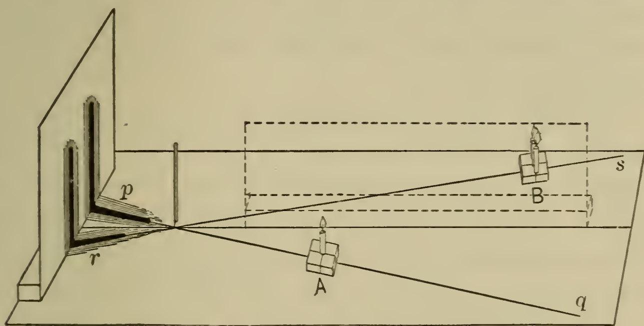

FIG. 39.—Rumford's Photometer.

equal small angles with the perpendicular and meeting the screen. On the perpendicular is placed a second cardboard screen, so as to shield the two lights one from the other.

Operations. — (*a*) At the centre of the block *A* mount one of the candles, and along the diameter of *B* mount the other four candles close together, and one behind another.

(*b*) Light the candles, bend the wicks down a little, and let them burn for a few moments till their flames are of equal size. If necessary, trim them to make them so.

(*c*) Move *A* along with a diameter on the line *pq* until the axis of the candle is, say, 25 cm. from the screen. Move the diameter of *B* along the line *rs*, and note the two shadows of the rod which are caused

by the two lights. If the black parts (umbras) of these shadows are not close together, move the screen toward the rod until they are.

(*d*) Now, with the greatest possible care, slide *B* backward or forward along *rs*, as may be necessary, until it is in such a position that the two shadows appear equally dark.

(*e*) Test the sensitiveness of the adjustment by moving the block forward or backward until each shadow in turn is manifestly less dense than the other. Record the amount of the change in distance. This represents your personal equation, or the distance within which you can set with certainty.

(*f*) Measure and record the distance from the screen to the middle of the line of four candles. Do this by measuring to the end of the block and adding half its diameter.

(*g*) Place the candles so that the line joining their centres is perpendicular to *rs* and is bisected by it. Repeat (*d*), (*e*), and (*f*).

(*h*) Change the one candle to a distance of, say, 40 cm. from the screen, and repeat all the previous operations.

Data. — Record the quantities opposite their proper headings. Make a vertical column for each setting.

Sources of Error. — State how errors may arise (*a*) in setting, (*b*) in reading distances, (*c*) in assuming that the candles radiate equal amounts of light.

Inferences. — We assume that when the shadows are equally black the screen is equally illuminated by the two lights.

NUMERICAL DATA

Settings	1	2
Distance pA		
Distance rB		
Ratio $\frac{rB}{pA}$		
Light emitted by A	1	
Light emitted by B	4	

(*a*) If four candles at the distance rB give the *same illumination to the screen* as one at distance pA, what is the intensity of the illumination by *one* candle at rB as compared with that by the one candle at pA?

(*b*) What must be done with the ratio of the distances $\frac{rB}{pA}$ in order to make it equal to the ratio of the intensities *with which one candle illuminates the screen*, at these two distances respectively? (Reduce both ratios to their lowest terms, expressing that of the distances as a mixed decimal number, if necessary.)

(*c*) Can the decimal remainder be fairly ascribed to experimental errors?

(*d*) If so, state the law that has been verified by your results.

OPTIONAL HOME WORK

SHADOW METHOD.—Prepare 3 squares of stiff pasteboard, *a* 1 inch, *b* 2 inches, and *c* 6 inches on a side, and block their areas off in square inches. The screens may be supported by knitting needles stuck in blocks of wood. Place a tin screen with a small hole in it just in front of a candle flame so as to have your source of light reduced nearly to a point. Place *a* 6 in. in front of the source, and move *b* to where *a*'s shadow just covers it; then remove *a*, and see that all the light which fell on it now falls on *b*. Their areas are as 1 to 4: how do their intensities of illmuination compare? Measure their distances from the source and compare the ratio of their illuminations with that of their distances. Do the same with *a* and *c*. Do your experiments verify the Law of Inverse Squares?

RUMFORD'S OR BUNSEN'S PHOTOMETER methods may easily be used at home, with materials that are found in every household. See *Light*, by Mayer and Barnard. (Appleton's, N. Y.).

EXERCISE NUMBER 51

PHOTOMETRY. CANDLE POWER OF A LAMP

REFERENCES. — These are the same as those for Exercise 49.

Purpose. — It is proposed to apply the law of inverse squares in measuring the candle power of a lamp by the method of Bunsen's photometer.

Apparatus. — In addition to the Bunsen's photometer, a kerosene lamp, gas burner, or incandescent electric lamp is supplied, also a small block or adjustable support for the candle, by means of which it may be raised so that the centre of its flame shall be at the same level as that of the lamp.

Operations and Data. — (*a*) Support the candle exactly over the centre of block *A* and the lamp over

that of B. Trim the candle wick, and elevate the candle till its flame is level with that of the lamp.

(*b*) Make several pairs of settings exactly as in Exercise 35, tabulating the readings and distances as before. Record also the ratios $\frac{(CB)^2}{(AB)^2}$. Perform the division for the result of each trial and tabulate the results. Record the average of these results as the candle power of the lamp. By reference to the law of inverse squares and the previous exercise, explain why the ratio $\frac{(CB)^2}{(AB)^2}$ represents the candle power of the lamp.

Lesson. — This is an example of a kind of physical measurement which has an extensive application in every lamp factory and gas works.

Exercise Number 52

REGULAR REFLECTION

References

A 269–274	GE 227	J 15–19
C 330–331	GP 291, 292, 295	M & T 356–359
C & C 239	H 450–452	W & H 369
	H & W 283	

Purpose. — It is proposed to verify the law of reflection of light.

Apparatus. — The appliances needed are: (*a*) a small rectangular piece of plane mirror, fastened by rubber bands to a bridge nut or rectangular block; (*b*) several pins; (*c*) a rule; (*d*) a protractor.

Operations. — (*a*) Near the inner margin of the note-book page, which should be held by weights so as to be perfectly flat, draw a fine straight line, MM', and place the edge of the silvered surface of the mirror exactly upon it.

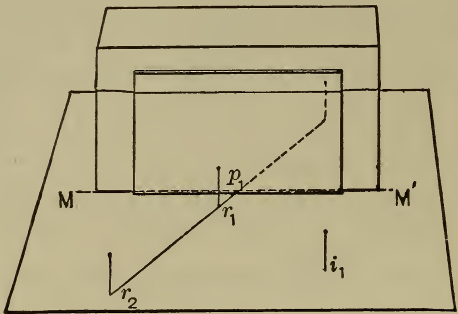

FIG. 40.—Showing how the mirror and pins are to be set up.

(*b*) Near the outer margin of the page, and a few centimeters to one side of the middle of MM', stick a pin, i_1, which may represent a luminous object and will be reflected in the mirror.

(*c*) On the other side of the middle of MM', and near the mirror, stick another pin, r_1.

(*d*) Now place the eye on a level with the page and sight along the line between the point r_1 and the point i_2 where the image of the pin i_1 appears to enter the reflected page.

(*e*) When the right position for the eye is accurately determined, stick another pin, r_2, into the page, near its outer margin, in such a position that it will exactly hide both the pin r_1 and the image, i_2, of the pin i_1.

(*f*) Remove the mirror, and with the rule draw the line r_2r_1, producing it until it intersects MM'. Mark the point of intersection, p. Also draw the

line i_1p. Then will pr_2 represent the reflected ray, p the point of reflection (and also of incidence), and i_1p the incident ray.

(g) At p erect a perpendicular to the line MM', and call it pq. Now, i_1pq is the angle of incidence and qpr_2 is the angle of reflection. Are they in the same plane? Measure them with the protractor.

(h) Repeat the experiment as many times as you can during the laboratory period. Use the same positions of the mirror and first pin, but other points for the second pin, so as to get different pairs of angles. Employ the same letters for the points; but use a *different style of lettering* for each trial.

Data. — Record results in tabular form.

DATA

TRIAL	ANGLE OF INCIDENCE	ANGLE OF REFLECTION	ERROR	PER CENT ERROR

Precautions — Sources of Error. — See that the mirror does not get displaced from the line, MM'. Draw fine lines exactly through the pinholes. Sight along the points of the pins just at the surface of the page. Errors may arise from lack of planeness in the mirror, inaccuracy in placing pins and drawing lines, and in measuring the angles.

Inference. — State the law that your experiments have verified.

Exercise Number 53

IMAGE IN A MIRROR

References

A 275, 276	GE 229–236	J 20–22
C 331, 332	GP 296, 297	M & T 356–359
C & C 242–245	H 453–455	W & H 370–372
	H & W 284	

Apparatus. — The appliances are the same as those in the preceding exercise.

Operations. — (*a*) Draw the line MM' across the middle of the note-book page, and place the mirror upon it precisely as in Exercise 52.

(*b*) Near a lower corner of the page draw an arrow about 4 cm. long, making an angle of about 60 degrees with MM', letter its extreme points i_1 and I_1.

(*c*) Proceeding exactly as in Exercise 52, locate as accurately as possible three reflected rays from i, and produce them behind MM', by dotted lines, until they intersect one another; obviously they should meet in a common point, i'_1, which is the image of the point i_1. This point was sighted at in Exercise 52, but was not definitely located, because the lines of the reflected rays were not extended behind the mirror.

(*d*) If the lines do not meet in a point, go over the work and correct the errors.

(*e*) Similarly locate the image I_2 of the point I_1, and draw the head and tail of the reflected arrow at the points that are the images of the head and tail of the real arrow. Also join the head and tail by a straight line representing the shaft of the reflected arrow. If time permits, the middle point of the shaft should be located precisely as were the two extreme points, and it will be found to fall into a straight line with them.

(*f*) Join i_1 and I_1 with i_2 and I_2, respectively, by straight lines intersecting MM' in points a and A. Measure accurately the distances I_1A and I_2A; also measure the distances of i_1 and i_2 from a.

(*g*) Measure the angles i_1aM and i_2aM, and compare their values. Do the same for I_1AM and I_2AM. Tabulate the results as follows:—

NUMERICAL DATA

Distances and Angles		Differences	Per Cent Errors
i_1a	i_2a		
I_1A	I_2A		
i_1aM	i_2aM		
I_1AM	I_2AM		

For the per cent error of distance, find by what per cent i_2a and I_2A differ from i_1a and I_1A, respectively.

For the per cent error of angle, find by what per cent each angle differs from 90 degrees.

Sources of Error. — Small errors in placing the pins are greatly magnified in their effect on the position of the image point. The farther apart the pins are placed, the less are the errors magnified.

Inferences. — (*a*) Are the per cent differences too large fairly to be ascribed to errors of experiment?

(*b*) State the *location* of the image (as to direction and distance from the mirror) compared with that of the object.

(*c*) Compare the object and image as to *size.*

(*d*) Describe the *position* of the image (erect, inverted, or laterally inverted).

(*e*) As to *character*, is the image real or virtual?

Additional Work. — If the instructor desire, this method may be employed exactly as above, to locate and describe the image of an arrow in a concave or convex cylindrical mirror.

Exercise Number 54

REFRACTIVE INDEX

References

A 284–286	GP 303–313	J 42–51
C 335–342	H 467–473	M & T 353–355
C & C 256–261	H & W 300–306	W & H 381–385
GE 232–237		

Purpose. — The refractive index of glass with reference to air is to be determined.

Apparatus. — The apparatus needed consists of pins, dividers, draughtsman's triangle, rule, and a rectangular piece of plate-glass with two of its narrow parallel faces well polished.

Operations. — (*a*) Across the middle of the note-book page, draw a line, ss', to indicate the common surface of the glass and air. Place the glass flat upon the page, and bring the edge of one of the polished narrow faces into exact coincidence with the line ss'. The plate may be fastened in this position by bits of beeswax.

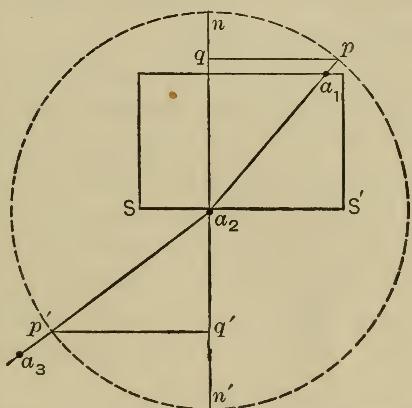

Fig. 41.—Illustrating the operations of Exercise 54.

(*b*) Stick a pin at a point, a_1, against the edge opposite to ss' and near one corner of the plate. Place the eye opposite this pin and on the level of the page. Now look through the glass at the pin. Note the position of the eye at which the image of the pin seen *through* the glass coincides with the pin itself as seen *above* the glass. What is the direction of the line from the pin to the eye with reference to the surface, ss'?

(*c*) Move the eye toward one side, keeping the image of the pin in sight, and noting the change in the position of the image as referred to that of the pin itself.

(*d*) Stick a pin, a_2, against the glass, and in line with the eye and the image of the first pin.

(*e*) Near the edge of the page stick a third pin, a_3, so as to hide a_2 and the image of a_1. See that the pins are erect and accurately placed, and that the glass has not moved from its first position.

(*f*) Now remove the glass; and draw the line a_1a_2, which is the path of the ray from a_1 through the glass to the point, a_2, in the common surface, ss', of the glass and air.

(*g*) Draw also a_2a_3, which is the path of the same ray through the air, after refraction at ss'. a_1a_2 is the incident ray; a_2 is the point of incidence and also of refraction; and a_2a_3 is the refracted ray.

(*h*) Through a_2 draw nn' perpendicular to ss'. This is called the *normal* to the common surface (or interface) of the two media.

(*i*) With a_2 as a centre, and as large a radius as practicable, describe a circumference cutting a_1a_2 in point p, and a_2a_3 in point p'. (a_1a_2 and a_2a_3 are to be extended, if necessary.) From p and p' drop perpendiculars to nn', cutting it in q and q' respectively.

(*j*) Measure pq and $p'q'$ as accurately as possible in millimeters. The quotient $\frac{pq}{p'q'}$ is the index of refraction from glass to air, and this ratio inverted, *i.e.* $\frac{p'q'}{pq}$ $(= m)$, is the index of refraction from air to glass, or, in other words, the refractive index of glass referred to air.

(*k*) Repeat the operations as many times as the time will permit, using each time a different angle of incidence. Record values of $p'q'$, pq, and the refractive index, m, in a tabular form of three columns. Note also whether the values of m are equal within the limits of experimental error, and record the mean value of m.

Sources of Error. — (*a*) The edge of the glass may not exactly coincide with the line ss'.

(*b*) Errors may arise from personal equation in setting the pins; also in construction and measurement. The lines should be drawn as fine as possible with a sharp-pointed lead pencil.

Lessons. — Refractive indices are very important in the calculations according to which the lenses and prisms used in all optical work are ground. Does refraction occur if the incident ray is perpendicular to the interface? State two laws of refraction which are verified by your observations.

If R = the radius of the circle, i the angle of incidence, and r the angle of refraction,

$$\sin i = \frac{pq}{R} \text{ and } \sin r = \frac{p'q'}{R};$$

whence the Index of Refraction (*from glass to air*),

$$\frac{1}{m} = \frac{\sin i}{\sin r} = \frac{\frac{pq}{R}}{\frac{p'q'}{R}} = \frac{pq}{p'q'}.$$

In accurate measurements of indices of refraction the angles themselves are read off on an accurately graduated circle fitted with a vernier and a magnifying glass. The instrument thus used is called a spectrometer.

Additional Work. — If the student have time it will be profitable to find by trial the approximate value of the critical angle, *i.e.* the angle of incidence that corresponds to the maximum (90°) angle of refraction, and to find the image of the pin which results from total reflection of the incident waves at the surface, ss'.

Exercise Number 55

FOCAL LENGTH OF A LENS

References

A 290–293, 318–323	H 477–480, 513–522
C 348–350, 352, 353, 355–359	H & W 310–319
C & C 269–272, 295–304	J 60–67, 84–87
GE 238–240, 270–275	M & T 350–352, 355, 360–367
GP 315–320, 327, 389–391	W & H 386, 403–405, 416

Purpose. — The purpose of this exercise is to determine the principal focal distance of a convex lens, and to investigate the effect upon its focal length of combining with it, firstly, another convex lens, and, secondly, a concave lens.

Apparatus. — A metric rule is mounted on a support so that it can be turned about either a horizontal or a vertical axis. Three support blocks are fitted to the rule, as shown. The rule fits into the rectangular groove, its upper surface being flush with the upper face of the block, which is held in place by two stiff rubber bands. Wire nails are stuck upright into the block, and over them at top and bottom are stretched a pair of rubber bands, into which can be slipped a lens or a small cardboard screen. This

arrangement allows the lens or screen to rest directly against the scale divisions of the rule.

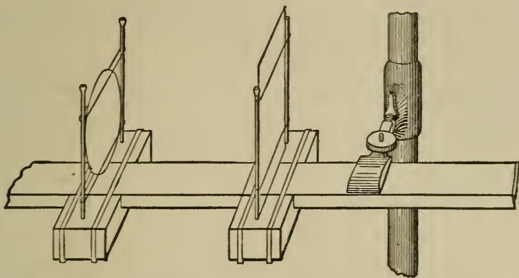

FIG. 42.—Rule and support blocks, mounted in a clamp so that they may be turned in any direction.

Two double convex lenses, unmounted, and each having a focal length of from 10 to 20 cm., and a concave lens, are provided.

Operations. — (*a*) Slip the blocks, *A* and *B*, on to the rule. Place a double convex lens between the uprights of *A* and the screen between those of *B*.

(*b*) See that the curtains are pulled about two-thirds of the way down so as partially to darken the room.

(*c*) Point the rule toward the most distant bright object that is visible through one of the windows, and, having the lens toward the window and between the latter and the screen, move the screen toward the lens or away from it until a perfectly distinct inverted image of the distant object appears upon the screen.

(*d*) Read on the rule the positions of the lens and the screen, and by subtraction deduce the distance

between them. Make at least three independent settings, changing the position of the lens on the rule each time.

(*e*) Place a second convex lens in front of the first and repeat the observations.

(*f*) Replace the second convex lens by a concave lens and repeat the operations. The two lenses should not be more than two centimeters apart.

Data. — Tabulate all of the readings. In each observation the focal length is the difference between the lens reading and the screen reading. In each case, record the average of the differences as the mean focal length of the lens or of the combination. Record the letters which are marked on the lenses, so that they may be recognized when wanted again.

Sources of Error. — From what sources may errors arise?

Inferences. — (*a*) In obtaining the principal focal distance, why should a distant object be chosen? (With a long focus lens the object should be infinitely distant, but with a lens of 10 or 20 cm. focal length, an object two or three hundred feet away will do.) (Why?)

(*b*) What two optical instruments are represented by the single convex lens and screen thus combined?

(*c*) When a second convex lens is placed in front of the first, what is the effect upon the focal length of the first lens?

(*d*) What is the effect of a concave lens? What kinds of cases of defective sight are corrected by applying the principles illustrated in (*c*) and (*d*)?

Exercise Number 56

CONJUGATE FOCI OF A CONVEX LENS

References

A 290–293, 318–323
C 350–359
C & C 273–275, 295–304
GE 241–246, 270–275
GP 315–327, 384–392
H 477–484, 513–520
H & W 309–319
J 68–80, 84–87
M & T 360–375
W & H 388–390, 410–416

Purpose. — The purpose of this exercise is (*a*) to investigate the conditions in accordance with which images are formed by a double convex lens, and (*b*) to verify the law of conjugate foci.

Apparatus. — The convex lens, rule, and blocks of Exercise 55 may be used, or, if preferred, the blocks of Exercises 49 and 51. In the latter case the rule should be fastened by brads to a smooth board, whose ends may be supported by blocks, at the proper height above the table. The lens and screen are to be mounted at the centres of the blocks just as in Exercise 55. The box suggested in Exercise 49 may easily be adapted to enclose either apparatus, and, if available, should be used. The rule and sliding supports as used in this and the preceding exercises constitute a very simple *optical bench.* A source of light is also provided, and may be a candle, small lamp, gas jet, or an incandescent electric lamp. It should be enclosed by a suitable opaque chimney or tube,* perforated by a circular aperture about 2 c.m.

*Fig. 43, page 206.

in diameter at the height of the centre of the light. A pin is fastened (by solder or wax) so that its head projects into the aperture from below, and is an object of which a distinct image may conveniently be obtained.

Part A. Relations of Image to Object

Operations. — (*a*) The focal distance of the lens is known from the preceding exercise, or may be given by the instructor. Support the optical bench so that it is horizontal and the centre of lens and screen in line with the centre of the light and of the circular aperture, the aperture being exactly at the end of the rule. Place the lens at a distance, p, greater than twice focal distance from the aperture ($p > 2f$), slide the screen up close to the lens, and, moving the screen slowly away, watch for the image to appear upon it. When the image appears, move the screen gradually backward or forward until the image of the pin is as distinct as possible. (Another lens may be used as a magnifying glass for examining the image, if desired.)

(*b*) Examine the image. Is it real or virtual? Erect or inverted? Magnified or diminished? Is it located at a distance, p', $> 2f$ (greater than twice focal distance), $p' < 2f$, or $p' = 2f$? Tabulate these observations under the headings Character, Size, Position, and Location.

(*c*) Make the distance between lens and object equal to twice focal distance ($p = 2f$), and repeat operations and observations.

(*d*) Repeat with the lens nearer ($p < 2f$).

(*e*) Make $p=f$. Look *through* the lens at the object. Observe that light comes from it, but no image appears. The rays from each point of the source are now nearly parallel.

(*f*) Make $p<f$, and look through the lens toward the object. Tabulate observations as before.

Applications.—Optical Instruments.—(*a*) Which of the cases represents the eye, or the camera?

(*b*) Which represents the projecting lantern, or the camera when used for enlarging?

(*c*) Which case represents the magnifying glass?

(*d*) Which the "spot light" used on the stage?

(*e*) In cases (*a*) and (*d*) the screen may be removed and the image viewed from a point near the end of the bench that is opposite the object. A convex lens, placed at its focal distance *from where the screen was*, will act as a magnifier to increase the apparent size and distinctness of the object. The paths of the light waves are parallelized by the second lens, and are converged at points on the retina by the crystalline lens of the eye. In which of the two cases just indicated, do the two lenses represent the objective and eye piece of the refracting telescope? The objective and eyepiece of the compound microscope?

OPTIONAL PROBLEM

IMAGE SIZE AND DISTANCE.—Measure in cm. the distances of object and of image from lens, also their lengths. Express decimally the ratio of image distance to object distance, and the ratio of linear size of image to that of object. Tabulate

all the data for a number of different trials. State the relation of linear size of image to linear size of object in terms of their corresponding distances from the screen.

Part B. Conjugate Focal Distances

Repeat the operations of cases (a) and (b), Part A, and each time read on the rule the values of the distances of object and image from the lens. These we have called p and p' respectively. Make at least two settings for each of the two cases. In one trial place the screen at the end of the rule and move *the lens* till a distinct image appears on the screen, recording the values of p and p' as before. Now interchange the object and screen without disturbing the lens; observe, and state whether or not a distinct image is formed. Record these new values of p and p'.

Data. — For each setting, take the reciprocals of p and p', expressing them decimally. Add $\frac{1}{p}$ and $\frac{1}{p'}$ for each observation. Also find the value of $\frac{1}{f}$. Tabulate the values of p, p', $\frac{1}{p}$, and $\frac{1}{p'}$, and also $\frac{1}{p}+\frac{1}{p'}$ and $\frac{1}{f}$, placing each set of values in a vertical column, under its appropriate letter, corresponding values opposite one another.

Sources of Error. — State briefly the sources from which errors may arise.

Inference. — (a) Experimental errors aside, are the sums, $\frac{1}{p}+\frac{1}{p'}$, equal to one another?

(*b*) Find their average. Does it differ from $\frac{1}{f}$?

(*c*) By what per cent?

(*d*) If this per cent is small enough to be ascribed to experimental errors, express the law by a general formula.

(*e*) State the law in words. p and p' are called the conjugate focal distances, and f the principal focal distance.

Exercise Number 57

STUDY OF SPECTRA

References

A 295–300, 304–309, 318–323
C 346, 360
C & C 277–286
GE 249–259
GP 315, 329–342
H 486, 487, 500–506
H & W 320, 321
J 91–99
M & T 387–395
W & H 392–394, 397–402

Purpose. — In this exercise, the purpose is to investigate the composition of light emitted from different sources.

Apparatus. — In addition to the source of light and perforated chimney, Fig. 43, p. 206, a prism and a Bunsen burner are provided. The perforation in the chimney is covered with a plate, having in it a narrow horizontal slit.

Operations and Observations. — (*a*) Cut out a strip of white unglazed paper, about half a centimeter wide and three centimeters long. Fasten it to a piece of black cloth or to a black photographic card-mount,

and place it in strong light from the sun or sky. Stand so that the eye is about a meter from it, and look directly at it.

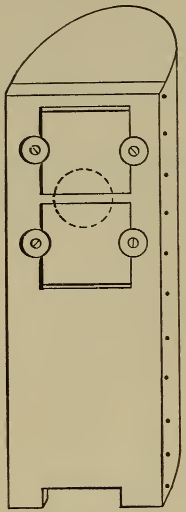

FIG. 43. — Chimney of wood and sheet iron for Exercises 56 and 57. The plates may be removed, leaving the circular aperture; or they may be pushed in from the sides, making a vertical slit.

(*b*) Now hold the prism in front of the eyes with its lower face about parallel to the line of sight, and its edges parallel to the length of the white strip. The strip will disappear; but if now the prism be raised a little without rotating, a beautifully colored image (spectrum) of the strip will be seen through the prism, apparently above where the strip is.

(*c*) Without otherwise changing the position of the prism, rotate it a little, first one way and then the other, about its axis, until the colors show with the greatest distinctness and brilliancy. This will occur at the *angle of minimum deviation;* that is, at the angle at which the light, incident on the prism from the strip,

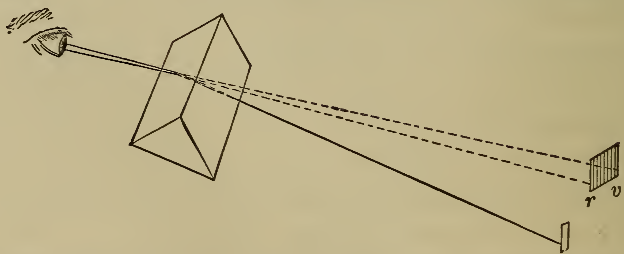

FIG. 44. — Showing position of the strip and its colored image, and the real and apparent paths of the rays.

is least turned from its original path. This position corresponds also, of course, to the minimum displacement of the image.

(*d*) Carefully examine the colors; and make a sketch of the spectrum, writing down the names of the colors in their order.

(*e*) Make a diagram of the arrangement, tracing the approximate direction which the light waves actually take in travelling from the strip to the eye, and also the directions which apparently they take in coming from the image.

(*f*) Which waves are deviated the least, those which cause the sensation of red, or those which cause the sensation of violet? Number the colors on the spectrum sketch in order, from the least deviated to the most deviated. What is the original source, and also the immediate source, of the waves which are thus separated? Why are their directions changed, some more than others?

(*g*) Place a second prism between the first prism and the eyes, the second being inverted as shown in Fig. 45. What is the effect? Are the waves recombined? What is "white light"?

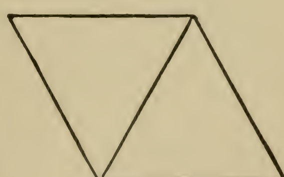

FIG. 45.

(*h*) Now place the lamp inside the chimney, the light opposite the horizontal slit and close to it, the room having been darkened. Find and examine the spectrum of the light coming through the slit, comparing it with that previously

given by reflection from the strip of paper. This is the spectrum from *white-hot carbon.* A stick with a spark on the end of it, or the filament of an incandescent electric lamp without the slit, will give the same result.

(*i*) Replace the lamp by the Bunsen burner, and after making sure that the part of the flame opposite the slit is colorless, let another student hold in the flame *below the slit* a platinum wire loop which has been moistened with distilled water and dipped into common salt or baking soda. Examine the spectrum, which is due to *sodium vapor.* What color appears most prominently?

(*j*) In like manner examine the spectra given by incandescent vapors of two or three other metals. The chemically pure bromides or chlorides of any of the following metals may be provided: potassium, calcium, strontium, and barium. Compare the colors and their relative positions. Does each metal have its own set of colors? Do they have the same positions as the corresponding colors in the solar or the carbon spectra?

Caution. — There should be a separate labelled platinum loop for each salt, and the greatest care should be exercised in order not to mix the salts; else the spectrum of the metal under examination will contain the colors of some other metals. It is extremely difficult to exclude the sodium band, because sodium is everywhere in the dust of the room. The sodium band will flash out whenever anything is dusted near the flame. Try it.

Lessons. — With suitably delicate apparatus (spectroscope), may the vapor spectra of some metals be used for detecting with certainty the presence of these metals in compounds? In the spectroscope a combination of lenses is used in order to make the light pass in a parallel beam from the slit to the prism, and to make the refracted images of the slit more distinct. Each colored image of the slit then appears as a fairly distinct band, and in a position which is perfectly definite for a given prism and for that particular wave length of light. The lack of distinctness of the bands in the case of the prism, when used without the lenses, is due to the overlapping of the images of the slit when radiations of different wave lengths are present.

If time is given for additional work, try the effect of viewing the carbon spectrum or the solar spectrum through pieces of colored glass, and state in your notes which colors are absorbed and which are transmitted by glass of each color examined.

Read the sections on spectrum analysis in the reference books to which you have access.

CHAPTER VII

APPENDICES

A. ERRORS AND SIGNIFICANT FIGURES

1. Errors.—Different measurements of the same quantity, even when made with the same care, are found to differ from one another,—the differences becoming less and less as the observer becomes more skillful, or as the accuracy of the instruments is increased. These differences are due to *experimental errors*, as distinguished from mistakes or blunders in either observation or calculation.

Experimental errors are called *errors of observation* when they result from variations in the judgment or perceptions of the observer, and *instrumental errors* when they result from imperfections of the instruments or apparatus employed.

Instrumental errors may often be determined, and a correction applied for each of them so as to eliminate their effects from the result.

The *error of a single observation* is the amount by which it differs from the result accepted by theory as the true one. The mathematical theory of probabilities shows that if a series of measurements has been made of the same quantity under the same conditions and with the same care, the mean or average of this series has much greater probability than any single observation, *i.e.* it is much more likely to be near the true value.

2. Mean of a Series.—The probability of the mean of four observations is twice that of a single one; of nine, three times; of sixteen, four times, and so on, *i.e.*, the probability of the mean is proportional to the square root of the number of observations. Besides increasing the probability of the mean, the taking of a series of observations makes it easier to detect blunders.

3. Significant Figures.—The magnitude of a physical quantity should be stated just as accurately as it has been

measured by the observer, no more, no less. For example, if the mean or average of a set of measurements of a given line, made with a metric rule, comes out 0.0204639 meters, the 2 nearest the left is the first significant figure. The two zeros at the left of this 2 are not significant figures, since they serve merely to locate the decimal point; but the zero after the 2 is significant, for it shows that the number of thousandths of a meter is more than twenty and less than twenty-one. Again, since the 4 represents four-tenths of the smallest division of the metric rule, it was obtained in the observations by estimating tenths of a division with the eye, and it is therefore in doubt because an error of at least one-tenth of a division is probable even in the judgment of a practiced observer. Thus we are not sure that the third significant figure of the true value may not be 3 or 5 instead of 4; and so it must be apparent that all figures in the fourth and subsequent significant places are wholly unknown to us. Since they have no significance, they should be rejected from the statement of the result. When discarding these figures, however, we should write 5 instead of 4 for the last or third significant figure, because 4.6 is nearer to 5 than it is to 4.

4. Rules for Precision of Numerical Statement.—In order that the numerical data may show correctly the degree of accuracy attained, as well as to save unnecessary labor in the calculations, the student should adopt and hold to the following rules in the reduction of his results.

1. In every statement of an observation, sum, difference, or average, retain the first doubtful figure, and reject all that follow it. If the first figure discarded is greater than 5, increase by one the last figure retained. If the figure in the last place to be retained in accordance with the rule is a zero, retain such zero. Example,—write 25.20 cm. instead of 25.2 in a case where the quantity is measured to hundredths of a centimeter, and found to be nearer to twenty-five and twenty hundredths than to twenty-five and nineteen hundredths or twenty-five and twenty one hundredths.

2. In products, quotients, and partial products, retain only as many significant figures, counting from the first at the left, as there are in the measured factor having the least number of significant places in accordance with Rule 1.

B. METHODS OF MEASURING LENGTHS

1. Use of a Rule.—Place the rule on edge so as to bring the division marks into contact with the line to be measured. In reading or setting the rule at any point stand directly in front of the point and sight downward at it along the division lines of the rule, thus avoiding the error of parallax. If the line is longer than the rule, mark the position of the end of the rule by a straight edged bit of paper and measure again from the mark. On a long line measure to the nearest millimeter. In measuring a line less than 10 cm. long estimate in tenths any remainder less than a millimeter thus: if the remainder is just perceptible call it 0.1 mm., if just perceptibly less or more than a quarter millimeter call it 0.2 or 0.3 and so on. If the result is to be expressed in meters and it is (say) 2 m. + 25 cm. + 9 mm. + 0.6 mm., write it 2.2596 m. If it is to be expressed in centimeters, write it 225.96 cm., *i.e.*, always express the result as a certain number of units and a decimal fraction thereof. If very accurate measurements are to be made with a rule, it is better not to use the end divisions, as the rule may be slightly worn at the ends. If the end divisions are rejected do not forget to take account of it in adding up the units of length for the final result. In measuring a quantity, a series of measurements is usually taken; and the individual measurements and their mean should be tabulated. (Cf. Appendix A Art. 2.)

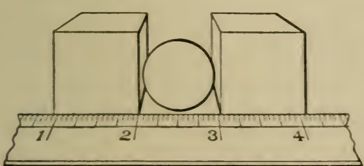

Fig. 46.

2. Use of Squared Blocks.—Fig. 46 shows a method of measuring the diameter of a round body. The inner planes of the blocks, being tangent planes, are perpendicular to the ends of the diameter. Therefore when the rule is placed as shown, the part of it included between these planes is parallel to the diameter and hence equal to it (parallel lines included between parallel planes are equal). Sight along the scale divisions to avoid parallax.

3. Use of Calipers.—By tapping lightly on the inner or the outer edge of one leg of the calipers, separate the tips or

bring them together, so that they just touch opposite ends of the diameter to be measured. With very little practice one can *feel* if the tips are too tight or too loose on the opposite surfaces of the body that he is measuring. Apply the calipers to the rule so that the inner face of one tip just splits a division line of the rule, then read the position of the inner face of the other tip to tenths of the smallest division. Avoid parallax. The difference between the readings is the length to be determined.

4. Use of the Vernier Slide Caliper.—(*a*) Loosen the set screw, *s* (Fig 47); and, grasping the scale in the right hand, press the thumb against the little projection, *p*, below the vernier till the movable jaw withdraws from the fixed one. Now place the body between the jaws; and, with the thumb on the projection, press the jaws together against the two surfaces at the extremities of the diameter that is to be measured, so that they are just in contact with these surfaces.

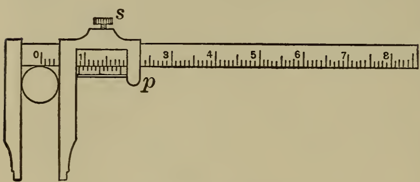

Fig. 47.—Vernier Slide Caliper.

(*b*) By means of the set screw, fasten the movable jaw in position, remove the cylinder, and take the reading of the caliper in accordance with the rule that follows.

Read and record the number of centimeters and whole millimeters from the zero of the scale to the zero of the vernier; and add the number of tenths of a millimeter in the remainder. This is denoted by the number of the line on the vernier which most nearly coincides with some line on the scale: *e.g.* if line number 3 on the vernier coincides with some line on the scale, the remainder is .3 mm. Avoid parallax.

In order to understand why this is so, notice that the vernier scale is 9 mm. long and is divided into 10 equal parts; hence, each vernier division is .9 mm. long. On the other hand each division of the fixed scale is 1.0 mm. long. Therefore when vernier line 3 coincides with some fixed scale line, vernier line 2 falls .1 mm. short of the fixed scale line next to the left of it. It is obvious also that vernier line 1 must fall .2 mm. short of the fixed scale line next to the left of it. Finally the vernier

line 0 must fall .3 mm. short of the fixed scale line next to the left of it. But this space of .3 mm. is the fractional part of a millimeter that was to be measured.

Note that the *first line* on the vernier is *zero.*

In some verniers 20 divisions of the vernier = 19 of the fixed scale, in others 25 of the vernier = 24 of the scale and so on. The principle is precisely the same.

If the student has difficulty in understanding the principle of the vernier, let him practice reading and reasoning as above, using a large model scale and vernier which he can easily make of wood or of cardboard, the fixed scale divisions being each 1 cm. long and the vernier scale divisions being each .9 cm. (9 mm.) long.

5. Use of the Micrometer Screw Caliper. — In one kind of micrometer caliper, the pitch of the screw (distance between two adjacent threads, measured parallel to the axis) is 1 mm.; and the circumference of the head is divided by a circular scale into one hundred equal parts. In another kind, (Fig. 48), the pitch is ½ mm.; and the circular scale has fifty equal parts. When the end of the screw rests against the stop, *B* (without strain), the edge of the circular scale should coincide with the zero mark of the linear scale, *a*; and the zero line of the circular scale should exactly coincide with the horizontal reference line.

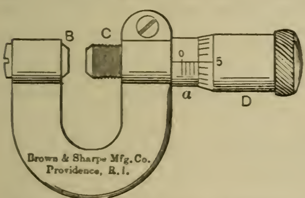

Fig. 48.—Micrometer Caliper. Pitch ½ mm. Circular Scale in 50 equal parts.

It should be noticed that in the first kind of micrometer caliper, the zero mark of the circular scale is identical with the 1.00 mark; and in the second kind it is identical with the .50 mark.

In the first kind of micrometer caliper, if the head of the screw is given one complete turn toward you, the screw end retires from the stop to a distance equal to the pitch of the screw (1 mm.); and the edge of the circular scale will coincide with the division 1 on the linear scale, which therefore denotes the distance in millimeters between the screw and the stop. Also, the zero mark of the circular scale will again coincide with the reference mark. Now if the head be turned farther

around till the division numbered 25 coincides with the reference line, the screw has retired from the stop a further distance equal to twenty-five hundredths of the pitch of the screw (*i.e.* .25 mm.). Similarly, if the screw has been turned so that the linear scale shows seven and a fraction of its millimeter spaces, and the 69th division of the circular scale coincides with the reference line, it is clear that the screw has turned through seven and sixty-nine hundredths revolutions, and the screw end is distant from the stop just 7.69 mm.

6. TO MEASURE THE DIAMETER OF A WIRE.—(*a*) Withdraw the screw from the stop and place a *straight* portion of the wire between them, so that it *lies flat* against the face of the stop. Turn the head till the face of the screw end rests against the wire firmly enough so that you can *just feel* the resistance.

(*b*) *To read the First Kind of Caliper.*—With the line of sight perpendicular to the scales at the reference line, read the number of whole millimeters on the linear scale, and the number of tenths and hundredths of millimeters on the circular scale.

(*c*) Determine the zero error by setting the screw end gently against the stop, and observing the scale readings as before. If the zero of the circular scale coincides with the reference line, no correction is required. If there is a small *negative* reading, it must be *added* to all readings of the caliper; and if there is a small *positive* reading, it must be *subtracted*. (Why?)

(*d*) *To read the Second Kind of Caliper.*—In this case also, each division of the circular scale corresponds to one-hundredth of a millimeter (because $\frac{1}{50}$ of $\frac{1}{2}$ mm. $= \frac{1}{100}$ mm.). Read the number of whole millimeters on the linear scale, and add the hundredths indicated on the circular scale just as directed above; but *if the fractional part of a millimeter exposed on the linear scale is greater than one-half, then* .50 *must be added* to the reading, in order to state correctly the fractional part. (Why?)

Thus, in Fig. 48, the caliper reads 4.50 mm. If D were turned so as to bring C nearer to B by $\frac{5}{50}$ of a revolution, the reading would be 4.45 mm.; but if D were turned so as to withdraw C by $\frac{23}{50}$ of a revolution, the corresponding reading would be $4.23 + .50 = 4.73$ mm.

(*e*) Several measurements should always be taken along different parts of the sample of wire. (Why?)

(*f*) Micrometers measuring in inches usually have a linear scale with units $\frac{1}{25}$ of an inch in length, and the circular scale divided into 40 equal parts. What fraction of an inch does one division of the circular scale measure?

(*g*) If the head of the screw is fairly large, it is easy to estimate tenths of the divisions of the circular scale and thus estimate thousandths of millimeters, or ten-thousandths of inches.

C. METHODS OF DETERMINING AREAS AND VOLUMES

1. Plane and Solid Geometrical Figures.—The areas of plane polygons and of surfaces of geometrical solids and the volumes of such solids may be obtained by calculation according to the rules of plane and solid geometry. The student should refer to his geometry for these rules whenever he finds it necessary to refresh his memory. The dimensions from which the areas or volumes are computed should each be the mean of a series of measurements, the smallest dimension being measured with the greatest care. Cf. Appendix A, Art. 2-4; also Appendix B.

2. Measuring Volume with a Graduate.—Compare the divisions on the graduate with the numbers, to learn how many cm.³ (cubic centimeters) each division represents. Thus if, as in Fig. 49, there are 5 spaces between the 60 and the 80 mark, then 5 divisions represent 20 cm.³; hence 1 division = 4 cm.³, and each tenth of a division = 0.4 cm.³ The single divisions of a graduate having 100 cm.³ capacity usually represent single cubic centimeters, and those of a 250 cm.³ graduate represent 2 cm.³ each. What would 0.1 of one of these divisions represent?

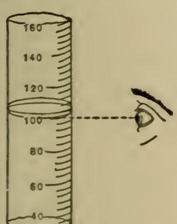

Fig. 49.—Showing the position of the eye when taking a reading.

To measure a liquid in such a graduate hold it at its upper end between the thumb and forefinger, allowing it to swing freely till it settles with its axis vertical. Then read on the scale the position of the middle line of the meniscus (*i.e.*, the saucer-shaped surface). Keep the eye on a level with the divisions as in Fig. 49. If

the position of the eye is correct the divisions will look straight instead of curved. Estimate the tenths of a division.

To measure a Solid, fill the graduate with water to any convenient division mark and take the reading as directed in the preceding paragraph. Incline the graduate and let the solid *slide* gently to the bottom, so as to avoid breaking the glass or splashing the water, and take the new reading. Obviously, the difference between the two readings is the volume of water displaced by the solid, and hence it is equal to the volume of the solid. Take the mean of several such determinations, using a different quantity of water, and set down all the data in a neat tabular form. If the readings are taken from the bottom of the meniscus both times the subtraction eliminates the error of assuming that to be the position the surface would have if plane; and since it is easier to read accurately from the bottom than from the middle the student is advised to do so.

D. METHODS OF MEASURING MASS

1. The Equal Arm Balance. Operations.—(*a*) See that the balance and the weights are free from dust.

(*b*) See that all the weights are present. To ascertain this easily, notice whether the sockets in which the larger weights belong are all filled; then see that all of the smaller weights are in order in a tray provided for the purpose and placed near the centre of the table, so that they will not be dropped upon the floor. The fractional denominations in most students' sets are as follows: decigrams, 5, 2, 1, 1; centigrams, 5, 2, 2, 1. *Report immediately if the set is incomplete or if the balance is not in perfect condition.*

(*c*) Adjust the balance to equilibrium by adding fine sand to the lighter pan till the pointer swings to equal distances on opposite sides of the zero position. If too much should be added, remove some.

(*d*) Place the object near the centre of one pan and the weights on the other, the largest in the centre and the others close around it. The weights should be tried in order, beginning with one known to be large enough. If the last weight be *too great, replace* it by the next smaller; if *too small, add* the next smaller. In this manner, continue with the systematic

trial of the weights until the opposite excursions of the pointer are equal.

(*e*) Add up the weights in the pan. Their sum is equal to the mass of the object.

(*f*) Add up the weights remaining and add their sum to the sum of those in the pan. Obviously, if the result is the total number of grams in the set, it is known that no mistake has been made in the count, and that no pieces have been lost.

(*g*) Remove the object to the other pan and weigh as before. Take the mean of the two weights thus obtained and record it as the mass of the object.

(*h*) When done with the weighing, see that both scales and weights are in perfect order, return the weights and pincers to their proper places. *These directions are to be followed in all weighings unless it be otherwise ordered.*

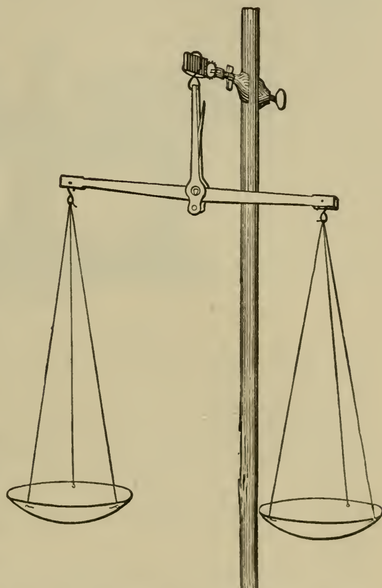

Fig. 50.—Showing a convenient method of supporting a "German hand balance."

Precautions.—(*a*) The weights and scales must be kept free from dust and liquids.

(*b*) The weights must be handled *with pincers only.*

(*c*) The balances should not be permitted to vibrate while object or weights are being placed in the pans.

These directions apply to balances that have no adjusting screw and no beam and pan arrests. *If the balances are provided with beam and pan arrests*, the levers that work these should be lifted each time before adding or removing object or weights, so as to prevent swinging during these operations. If there are no arrests, the pan may be held in the hand while

the load is being changed. *If there is a screw for adjusting to equilibrium*, this is turned toward the lighter side, instead of adding sand. Hand balances may be conveniently suspended upon a vertical support rod by means of a screw clamp as in Fig. 50. The pans should not be far above the surface of the table.

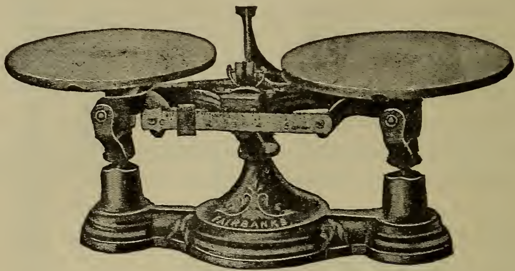

FIG. 51.—The Trip Scales.

2. THE TRIP SCALES. OPERATION. — (*a*) Place the slider at zero. (Fig. 51.)

(*b*) See that the ends of the knife-edge do not rub against the ends of the bearings. If they do so, the beam will not oscillate freely, but will come to rest rather suddenly. Move the beam very slightly forward or backward till there is no friction.

(*c*) In front of the pointer are two little nuts. Turn the right-hand nut toward you, so that the two nuts are unlocked; then turn both nuts toward the lighter pan till the balance is adjusted. Lock the nuts in place by turning them toward each other.

(*d*) Weigh as with the equal-arm balance to within 5 grams; then move the sliding weight along the graduated beam till equilibrium results, and read on the scale the position of the left edge of the slider.

(*e*) The scale reads grams and tenths up to 5 grams; this reading is to be added to the sum of the weights if they are on the right-hand pan, and subtracted if they are on the left. (Why?)

3. THE JOLLY BALANCE.—If one has calibrated a spring as in Exercise 7, he knows just the amount by which each gm.

elongates it. Therefore, if he wishes to weigh with it, all he needs to do is to take a reading of the pointer on the scale when there is no load on the pan, and then another when the object to be weighed is in the pan. The number of gms. that one scale division represents multiplied by the difference between the two scale readings is the mass of the body in gms. A spring mounted on a suitable adjustable support (like Fig. 4, but with more refined adjustments) is called a Jolly balance. If such a balance is to be used for *hydrostatic weighing*, as for Exercise 22, it usually has a second pan suspended below the first by a fine wire, and a movable shelf holding a vessel of water is placed at such a position that the lower pan will be submerged during each of the weighings. Then if r_0 is the reading with no load, r_1 that with the body on the upper pan, and r_2 that with it on the lower pan, the density of the body is numerically

$$D = \frac{r_1 - r_0}{r_1 - r_2},$$

for $r_1 - r_0$ represents the weight of the body, and $r_1 - r_2$ represents the buoyant force of the water on it.

If the simple apparatus of Fig. 4 is to be used in this way the vessel of water may be supported on a thin board placed on a large retort ring below the second clamp, c'.

If used for getting the density of a liquid (Exercise 22, Part B), the suspended solid takes the place of the lower pan, and if r_1, r_2, and r_3 are respectively the reading with the dry solid in air, that with it submerged in water, and that with it submerged in the liquid, the density of the liquid is

$$D = \frac{r_1 - r_3}{r_1 - r_2}. \quad \text{Why?}$$

The same principles apply if the Jolly balance is used for Exercises 20 or 21, or for measuring any forces whatever, since any elongation (difference between two readings) multiplied by the force that produces an elongation of 1 scale division equals the amount of force that produces the observed elongation.

4. A RUBBER BAND DYNAMOMETER, may be used on the same principle as the Jolly balance for measuring forces in any direction, and is an excellent substitute for a spring balance for schools where funds for equipment are limited.

E. BAROMETER

Reading the Barometer.—(*a*) Turn the screw *O* (Fig. 52) to the left until the mercury in the cistern is seen to withdraw below the little ivory point at *B*. This ivory point represents the zero end of the scale that is attached to the metal case.

(*b*) Looking so that the line of sight is tangent to the mercury in the cistern, slowly turn the screw *O* to the right until the ivory point *just meets* its image reflected in the mercury.

(*c*) By turning the screw *D* from you, raise the lower edge of the sliding (or vernier) scale, *C*, until you can see over the upper surface of the mercury column.

(*d*) Place the eye on a level with the highest point of the mercury column, and by reversing the screw *D* lower the vernier till its zero line appears just tangent to the curved surface of the mercury.

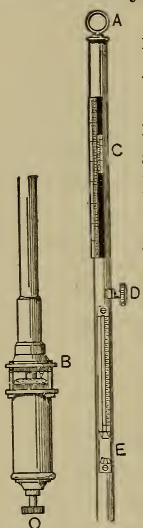

Fig. 52.—U.S. Weather Bureau Standard Station Barometer.

(*e*) Read the scale and vernier precisely as directed for the vernier slide caliper, Appendix B, Art. 4.

(*f*) If the barometer reading is to be taken in inches instead of in centimeters, note that inches and tenths are measured by the fixed scale and hundredths of inches by the vernier.

Correction for Temperature.—The temperature of the room being higher than 0° C., the mercury column and the scale by which it is measured are both expanded by the heat, and therefore are longer than they would be at 0°. As the readings of air pressure are customarily based upon the supposition that the temperature of the mercury is zero, it is usual to observe the temperature of the barometer by means of the "attached thermometer" (*E*, Fig. 52), and to correct the observed height of the column for the error due to expansion. The correction is the difference between the expansion of the mercury column and that of the brass scale by which it is measured. (Would a correction be necessary if both expanded equally?) Since the temperature of the room is *above* zero, and since the mercury expands *more* than does the brass, the observed height is too great, and the correction

is to be subtracted. The amount of the correction is jointly proportional to the length and to the temperature of the mercury column.

The corrections for all pressures and temperatures have been calculated, and are published in the tables of the United States Weather Bureau. Unfortunately, the pressures are expressed in inches and the temperature in Fahrenheit degrees. So that the barometer should be read accordingly, if its indication is to be thus corrected.

To Find the Correction for Temperature, consult the *Table for Reduction to* 32° *F.*, in accordance with the rule given below.

In the vertical column at the left find the temperature that was observed on the attached thermometer. Follow the line of this number to the right till you reach a column of figures, headed by the pressure-reading that you observed. In this vertical column, the number directly opposite your attached thermometer-reading is the correction required. If the exact temperature and pressure that you observed are not shown in the table, select the nearest values that are tabulated.

Other Corrections.—When readings simultaneous *at different places* are to be compared, they are all reduced to what they would be at sea level. The capillary depression of the mercury in the tube is corrected by permanently lowering the scale.

F. SUGGESTIONS CONCERNING APPARATUS

1. Exercises 1 and 2. This apparatus is easily "home made." Length 150 to 200 cm., width 6 cm., thickness 2 cm. The weights may be cast from lead in a plaster of Paris mold. Holes are drilled in them and in the wooden rod; and they are fastened by wire nails fitting snugly in these holes. Balls of any size with hooks may be had from apparatus dealers. The ball must be heavy enough to hold the pendulum in equilibrium as shown.

2. Ex 5. If so ordered the dealers will furnish the cars with hooks both behind and in front. The Author uses strips of plate glass to run the cars on. They may be had from wholesale glass dealers. They are remnants and are inexpensive (about 85c each). Mr. J. E. Crabbe of Cleveland uses very

successfully the rubber from an old golf ball instead of rubber tubing. With mass of car and load equal to 1,000 gm. or more, the masses may easily be adjusted to equality within 20 gm. or 2 per cent.

3. Ex. 7. Slotted weights for this Exercise and several others are easily cut with tinner's snips from sheet lead. The platform on which to suspend them may consist of a small square of thin board with a long stiff wire hook stuck into it perpendicularly at its center. The platform may be loaded with enough lead to give it the same mass as one of the slotted weights. Pans to hold ordinary weights may be made by soldering a wire bale on to a small pie pan. The weight of the pan may be adjusted as desired with drops of melted solder. These pans and weights are used in several other Exercises.

4. Ex. 9. Expensive pulleys are not necessary, but if cheap ones from the hardware store are used, the weights used with them should be as heavy as possible. For large weights, "blank" bridge nuts may be bought at wholesale hardware dealers'. They are very cheap, are of various sizes, and those of a given size are so nearly of uniform weight that they may be adjusted to equality with a coarse file. (For platform support see Art. 3 above.)

5. Ex. 10. Plumber's safety chain may be bought by the pound of wholesale hardware dealers, and key rings by the dozen. Spring balances of all kinds are sold by Fairbanks, Morse & Co. (Chicago or Cleveland). The apparatus dealers sell a kind that have flat backs. These are the best for the purpose. The clamp hooks may be made from the drawing by any blacksmith.

6. Ex. 11. The Author uses for inclined planes, boards about 6 ft. x 6 in. x $\frac{7}{8}$ in., as shown in Fig. 7. Narrow strips are nailed on the sides to keep the cars from running off. The same glass strips and cars (cf. Art. 2 above) as are used in Ex. 5 are used here. If the teacher prefers to use a pulley and weights instead of a spring balance, it may be set into a slot just above the upper end of the glass strip. (For pans and weights see Art. 3 above.)

7. Ex. 12. The post, strut and back-board for this exercise may be made by any one who can use a saw and a plane, and drive a nail. The upright that supports the cross bar of the

table may be used for the post; and the back-board may be clamped to it with a carpenter's hand screw. The tie may be attached to a screw eye in the upright.

8. Ex. 13. [Exercises 13, 14, 15, and 17 are all on moments. It is not expected that all of these be required of every student.] The wire clevis may be made of No. 16 German silver wire with a pair of square and a pair of round pliers. The holes in the meter stick should be smoothly drilled. Apparatus dealers sell clevises which slip over the bar, and with these the holes will be unnecessary. (For pans and weights see Art. 3 above.) For measuring vertical upward forces an equal arm balance may be used. Attach a cord to one pan, and measure the pull on this cord by weights on the other pan. This device is more accurate than a spring balance or a pulley.

9. Ex. 15. This exercise is useful in combating the too common assumption by students that every force is a weight. Instead of suspending the bar by a wire, it may be supported by small wheels at A and B. Use a square card or draftsman's triangle to test the right angles at p_1, p_2, and p_3.

10. Ex. 17. The apparatus of Ex. 13 may be used, with the addition of the lead strap.

11. Ex. 18. The Author prefers to defer this experiment till the class is about to begin the study of sound. He takes it up in connection with a *brief and informal* study of the chapters on wave motion and simple Harmonic motion as given in the Mann & Twiss *Physics*, Chapters XIV and XV. Excellent suspension clamps for pendulums are sold by apparatus dealers, but the slit cork answers admirably.

12. Ex. 19. Cylindrical graduates of 250 cm.^{3} capacity are best for this Exercise and are used in several others. These and nearly all glassware, thermometers, etc. may be bought very cheaply if *imported duty free* through the Bausch & Lomb Optical Company or any of the other well-known apparatus dealers.

Problem (a) The Hall pressure gauge is sold by all the dealers (price 75c). It shows the equality of pressures at a given depth perfectly but is of no use to prove quantitatively that the pressure is proportional to the depth.

13. Ex. 24. The 3-way glass tube for this experiment is more convenient than the usual Y form if made as follows.

Hold a T tube in a fish tail flame, the plane of the T being horizontal, and bend each of the three arms vertically downward. With this form the rubber tube extending to the mouth-piece will not "kink." The best dish for this experiment is cylindrical, the diameter being about 3 inches and the height 2 inches. See Bausch & Lomb's catalogue.

14. Ex. 25. Blank hydrometers and paper millimeter scales may be had from the apparatus dealers. If the teacher prefer to shorten the exercise the tests may be made with a ready made hydrometer or lactometer. The Babcock cream test is easily made and if the school can afford the apparatus it will arouse much interest if given as an optional experiment. If the apparatus is ordered, ask for full directions to accompany it.

15. Ex. 26. The operations of working glass and corks can best be shown to the students by the teacher. After being shown, one can learn only by practice. See Threlfall's *Laboratory Arts* and Shenstone's *Methods of Glass Blowing.*

16. Ex. 27. If the teacher wishes to make his own Boyle's Law Apparatus, he will find the form described in this experiment the easiest to make; and it works as well as any. The tubes fitted with the caps and screws may be obtained from The Central Scientific Co., Chicago, or the L. E. Knott Apparatus Co., Boston.

17. Ex. 28. Paper scale thermometers, imported duty free, cost about 40c, but some of them are so inaccurate as to give very poor results. A much better thermometer, with the scale etched in the glass, costs about 90c. The boiler should have the water gauge and screw top, and may be made fairly tight if a rubber band is used for packing after the manner of a Mason fruit jar. If the boiler leaks, the pressure experiments will not succeed. The pressure gauge suggested by the Author is made from a thistle tube and a paper millimeter scale. The thistle top prevents the mercury from overflowing, and permits the gauge to act as a safety valve.

18. Ex. 29. The Calorimeter of Exercise 30-32 is suitable for this experiment.

19. Ex. 35 and 36. "Home made" telegraph instruments are easy to make. Many of the Author's students forge their levers and magnets from iron and mount them in hard wood bearings. The ingenuity of some boys if you get them started

is marvelous. They will make workable apparatus out of all kinds of junk.

20. Ex. 38. This is regarded by the Author as one of the best experiments in the course. The coils furnished for this purpose by the dealers are expensive, but cheap substitutes that will work well are easily made. Wind the wire on a wooden reel, remove the one end of the reel, slip the coil off, and bind it all round with adhesive tape. The coils shown in Figs. 138 and 139 of the Mann & Twiss *Physics* were made in this way and work satisfactorily. See Galvanometers and Shunts, Art. 21, below.

21. Ex. 39. GALVANOMETERS are of so many different patterns that it is useless to try to give instructions in a manual intended for general use. D'Arsonval's filling all the requirements of this course and the Mann & Twiss Text may be bought from the Central Scientific Co., Chicago, and the L. E. Knott Apparatus Co., Boston, for about $6.00 each. Circulars giving full directions for setting up and reading the instruments, will be furnished with them if asked for.

SHUNTS.—*A strong current should never be sent through a sensitive galvanometer.* In beginning an experiment, it is always best to shunt the galvanometer by connecting its two binding-posts across by means of a short wire, so that only a small fraction of the current goes through it. When the current is so small that the galvanometer is insensitive, a shunt of higher resistance may be used, or the shunt may be discarded.

22. Ex. 41. SCRATCH BRUSHES and other plater's materials may be bought from dealers in plater's supplies.

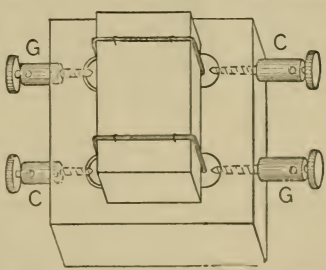

FIG. 53.—Commutator. The wires leading from the galvanometer are inserted at posts *GG*, and those leading from the current circuit at posts *CC*.

COMMUTATOR.—In many experiments it is necessary that the current passing through the galvanometer be quickly reversed. Accordingly, a commutator, or reversing switch, is provided. A convenient and inexpensive device is shown in Fig. 53.

The connections are made as shown, by wires dipping into holes containing mercury. To reverse the current through the galvanometer, lift the top, turn it through a right angle, and replace it. To break the current, leave off the cover.

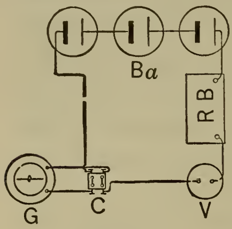

FIG. 54.

When measuring current strength with a galvanometer, or when standardizing a galvanometer with an electrolytic cell (copper voltameter), the connections should be made so that the current from the battery may be reversed through the galvanometer, but not through the voltameter. In such a case the apparatus is arranged as in Fig. 54, in which *G* represents the galvanometer, *Ba* the battery, *V* the voltameter, and *RB* a resistance box for regulating the strength of the current. When an ammeter or volt-meter is being standardized, no commutator is needed, because these instruments read on one side of the zero only.

THE COPPER VOLTAMETER, Problem *b*.—This experiment requires a balance and weights that are accurate to a milligram. It is not recommended for the younger students.

23. RENEWING EXHAUSTED DRY CELLS.—Remove the pasteboard cover, punch holes through the zinc walls, and place the cell in a jar of sal ammoniac solution. It will work as well as ever.

24. Ex. 43. Instead of smoking the glass it may be painted with a thin paste made of whiting and alcohol. The alcohol evaporates, leaving a clean white coat which may be easily removed.

25. Ex. 52. Instead of mirrors the glass plates of Ex. 54 may be used. Screen off the light from the rear and use the reflection from the front surface. This avoids errors which result from refraction when the light enters the glass and is reflected from the back surface.

26. Ex. 57. This exercise is recommended for those schools where a good projection apparatus is not owned. The Author personally prefers to demonstrate these phenomena with the lantern, and also to place a spectroscope at the disposal of those students who wish to experiment themselves and may be trusted with it. A small direct vision spectroscope may be imported duty free from Germany for about $10.00.

G. PRESSURE AND TEMPERATURE OF WATER VAPOR

This table gives the pressure P in millimeters of mercury of saturated water vapor at the temperature $t°$ opposite which it appears. Any value of $t°$ also represents the boiling point when the atmospheric pressure has the corresponding value of P.

t	P	t	P	t	P
—5	3.2	17	14.4	75	288.8
—4	3.4	18	15.3	80	354.9
—3	3.7	19	16.3	85	433.2
—2	3.9	20	17.4	90	525.4
—1	4.2	21	18.5	95	633.6
0	4.6	22	19.6	96	657.4
1	4.9	23	20.9	97	681.8
2	5.3	24	22.2	98	707.1
3	5.7	25	23.5	98.2	712.3
4	6.1	26	25.0	98.4	717.4
5	6.5	27	26.5	98.6	722.6
6	7.0	28	28.1	98.8	727.9
7	7.5	29	29.7	99.0	733.2
8	8.0	30	31.5	99.2	738.5
9	8.5	35	41.8	99.4	743.8
10	9.1	40	54.9	99.6	749.2
11	9.8	45	71.4	99.8	754.7
12	10.4	50	92.0	100.0	760.0
13	11.1	55	117.5	100.2	765.5
14	11.9	60	148.8	100.4	771.0
15	12.7	65	187.0	100.6	776.5
16	13.5	70	233.1	100.8	782.1
				101.0	787.7

H. WAX, CEMENTS, SOLDERING

1. Soft Wax, indispensable for temporarily sticking anything to anything else, is made by melting and stirring together 40 parts of beeswax with 10 of Venice turpentine and 1 of rosin. When it is cold, cut it into sticks with a knife that has been dipped in gasoline, and wrap the sticks in paraffine paper and tinfoil.

2. Beeswax and Rosin Cement will stick almost any two

materials together air tight. It is made by melting together equal parts of beeswax and rosin. It may be cast in a thin cake by using a paraffined pasteboard box cover as a mold. Use it as you would sealing wax.

3. Cement for Joining Glass to Glass.—Boil 1 part of caustic potash with 3 of rosin, 5 of water, and 4 of plaster of Paris.

4. Soldering.—Articles to be soldered must first be thoroughly scraped *clean*, and be kept absolutely free from grease. The "*soldering copper*" should be kept clean and the tip covered with a bright coat of solder. It may be filed bright, heated, dipped in a *strongly acid* solution of chloride of zinc and then rubbed on a bar of solder. The *chloride of zinc solution* is made by dissolving sheet zinc scraps in hydrochloric acid, and is used as a flux on tin, lead, copper, or brass articles that are to be soldered. When used as a flux it need not be so strongly acid as when cleaning the soldering copper. *Rosin* is a good flux for iron and tin. The secret of success in soldering is to have the "copper" well tinned as above and *hot* (not red hot), and to have the article well cleaned and wet with the flux. Better have "two irons in the fire" so one will always be hot.

A Gas Furnace for heating the soldering coppers is a great convenience and is inexpensive.

Small articles may be conveniently soldered in a Bunsen flame, or with a mouth blowpipe. They must be held absolutely still until the melted solder has "set."

For Soldering Galvanometer Suspensions, make a special "copper" from a small copper rod. Drill the upper end and tap in a piece of iron telegraph wire. Bend the upper end of this wire into a handle.

I. REFERENCE BOOKS FOR TEACHERS

Much information that is nearly indispensable to physics teachers may be found in any of the books of the following list:

Elementary Practical Physics. Stewart & Gee. 3 vols. $4.85. The Macmillan Company.

Physical Manipulation. Pickering. 2 vols. $7.00. Houghton, Mifflin & Co.

Laboratory Arts. Threlfall. $1.50. The Macmillan Company.

The C. G. S. System of Units. Everett. $1.25. The Macmillan Company.

Instructions to Voluntary Observers. U. S. Weather Bureau.

The Barometer. U. S. Weather Bureau.

Methods of Glass Blowing. Shenstone. $0.80. Longmans & Co.

Physical Measurements. Kolrausch. D. Appleton & Co.

Physical Measurements. H. Whiting. 4 vols. D. C. Heath & Co.

Experiences Elementaires de Physique. 2 vols. H. Abraham. Paris Gauthier-Villars.